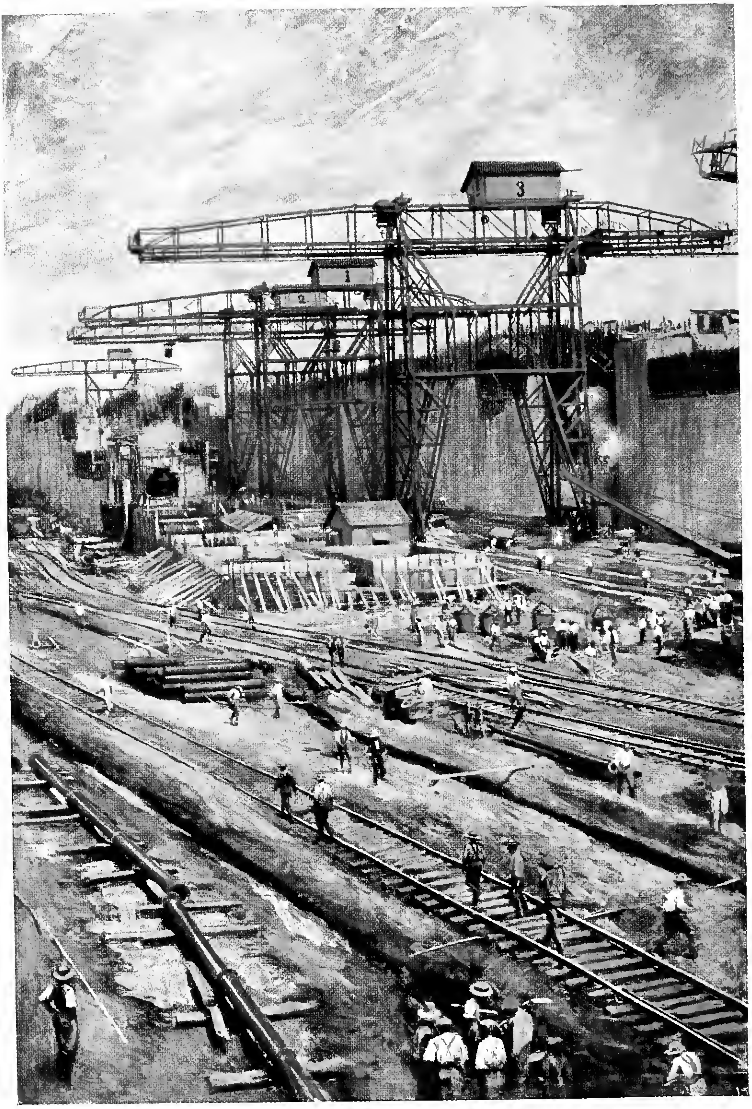
ALL ABOUT ENGINEERING



MAKING THE PANAMA CANAL

Note the huge cranes employed in building the locks

ALL ABOUT ENGINEERING

A BOOK FOR BOYS ON THE GREAT CIVIL AND MECHANICAL ENGINEERING WONDERS OF THE WORLD

BY

GORDON D. KNOX

With Two Colour Plates and many Illustrations from Photographs

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PREFACE

It is in the belief that there are few boys throughout the confines of the British Empire who are not more or less keenly interested in engineering that I have ventured to add one more volume to the many that have appeared during the last few years on various aspects of the subject. The all-comprehensiveness of engineering relieves me of any necessity for having to explain that the book does not pretend to cover the whole field of the subject, even though it could only do so imperfectly. I have treated it rather personally, dealing with those branches that have made the strongest appeal to me, and have been forced, in consequence, to omit all reference to others that some of my readers may justly think should have been included. A word of explanation is necessary, however, as to the almost complete absence of any direct reference to machines as such. I have avoided this aspect of the subject deliberately, because I wished rather to emphasise the character of those great exploits that we group together under the title of engineering works. I have gratefully to acknowledge the courtesy that I have received from editors of many papers, and to give my best thanks to the editors of *The Morning Post* and *The Standard* for leave to reprint

articles of my own that appeared in their columns, to the editors of *Engineering* for the free use that they allowed me to make of the articles that appeared in their pages on the Panama Canal, and on the harnessing of the Nile, to the editor of *The Technical World Magazine* for permission to reproduce the most thrilling account that I have ever read of bridge construction, and for much other assistance, and to the editor of *Munsey's Magazine* for a striking quotation from a most suggestive article on the passing of the horse. I have borrowed my material freely from the experts in different subjects, and am indebted particularly to Mr. Charles Bright's works on the telegraph; to Sir William Willcocks' accounts of the work done in Egypt and Mesopotamia; to the works of Alan Stevenson and Price Edwards on lighthouses and seamarks; to the reports of the National Physical Laboratory; to H.M. Office of Works, to Messrs. L. B. Mouchel and Partners, Ltd., and to the Associated Portland Cement Manufacturers, Ltd., for information on concrete; to the books of Mr. E. F. Knight, Mr. G. W. MacGeorge, Mr. Athol Maudslay, Mr. W. A. Forbes and Mr. A. C. Burmester, and to the Roorkee Treatise on Civil Engineering for information on roads, but above all on this subject to the kindness of Colonel R. E. Crompton, who placed much valuable information at my disposal; to Professor Frederick Soddy, who allowed me to make a long extract from his book on "The Interpretation of Radium"; to Messrs. J. and H. Maclaren, Messrs. Marshall, Sons and Co., and Messrs. John Fowler

and Co., for information on agricultural machinery ; to Mr. H. W. Hughes, whose "Text-book of Coal Mining" forms the basis of the chapter on Mining ; to Mr. A. Beeby Thompson's "Petroleum Mining and Oil Field Development" ; Mr. Archibald Williams' book on "The Romance of Mining," to which I am indebted for many hints ; to the work of Mr. Philip Phillipps on the Forth Bridge and other bridges ; to Messrs. Griffiths and Co. for their information as to the work of a contractor ; to Sir William Fitzmaurice's account of the London Sewer System ; to Professor John Perry's "Spinning Tops," and to a pamphlet by Dr. James G. Gray and Mr. George Burnside on the Motor Gyrostat ; to Mr. C. Prelini's and Mr. C. S. Hill's work on Tunnelling, and to Mr. Carl Staniforth for kindly giving me a most graphic history of the manufacture of a file, on which my own account is based. My thanks are also due, especially, to my colleague, Mr. E. H. Rann, for the loan of several papers and books from his library, to the Secretary of the University of London, University College, for the information he gave me on the making of an engineer, and to Mr. L. R. Gleason for the many suggestions he put forward while reading the proofs.

My best thanks are also due to Mrs. Marshall and her assistants for the rapidity and care with which they carried through the typing of what must have proved a troublesome manuscript.

Apart from these acknowledgments, I am conscious that I have borrowed also from other sources, as will be

seen from the references in the text. I have made a special point, where possible, of quoting from the actual accounts of those engineers who have left records of their own works, as, for instance, in the case of the Severn Tunnel, partly for their intrinsic interest, and partly that those who wish to pursue the subject farther may know where they can get the information at first hand. There must, I am afraid, prove to be cases where I have found it impossible to acknowledge my sources of information, as in the course of reading one acquires facts and forgets whence they have been derived. In conclusion, I would state that I have made every effort to avoid falling into mistakes while treating a technical subject popularly, but in view of the extensiveness of the subject, I would ask my readers' indulgence for any errors that they may detect.

GORDON D. KNOX.

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ALL ABOUT ENGINEERING

CHAPTER I

HISTORICAL

THE history of engineering may fairly be regarded as the history of the world's civilisation, and a good case could be made out for the view that it is through the engineering and mechanical skill of the few that man has reached to his present state of pre-eminence. It is a matter that requires no argument to show that the leisure which man has acquired has been won because he has used his brain to supplement the weakness of his physical strength, and it is at first sight an attractive enough view that it is because man exercised his special faculties that they grew and developed and made him pre-eminent. Such an interpretation is not, when rightly considered, inconsistent with the teaching of any school of biology; it can be brought within the scope of most hypotheses, and I will admit at once that I should have been inclined only a year ago to look on this as the simplest way of explaining man's progress, referring the development of man's brain to the fact that the force of circumstances compelled him to use his faculties, and that the race was propagated only or chiefly by those who enjoyed a slight differential advantage in these respects over their fellows. I had the

good fortune, however, last year to be present at the British Association meeting at Dundee, when Professor Elliot Smith read his presidential address before the section of Anthropology. In this, if I understood him right, he showed that it was rather the developing brain that moulded man's progress than his environment that forced his brain to undergo development. I must not make Professor Elliot Smith responsible for my own deductions. From the standpoint of my present subject, I should like to argue that the engineer has not only provided us with the material conditions that make civilisation possible, but that by drawing men's minds to things mechanical, he has forced their brains to develop, and in this way, too, has assisted him in his upward progress. The facts, however, do not fit in with this view, and we must avoid the temptation of saying, "so much the worse for the facts," and we shall be rewarded by getting the grander and larger idea that the brain is an organ spontaneously undergoing development, not perhaps independently of man's environment, but compelling him to secure an environment that shall be adapted to his requirements. And it is in performing this task that the engineer finds the scope for his greatest achievements.

Let us go back to the dawn of history. Glancing at the shattered remnants of the Stone Ages, we can catch a glimpse of the days when the engineer had no existence, of the days when the only roads were those trodden down by the feet of men and the hoofs of animals, when the only bridges were the casual tree trunks that had fallen across the stream, when the only dwelling was the natural cave. Of the dawn of engineering we have no record; it

is only in imagination that we can conceive of the birth of the idea of the wheel, of the wedge, and the development of the latter into its more complete and perfect form, the screw. We can speculate, if we care to, as to how men hit on these epoch-making ideas, but we have no knowledge of when or where they arose.

We shall be on surer ground if we try to estimate the engineering conditions of the old world as we know it from the remains that have come down to us from the Greeks and Romans. The Greeks, curiously enough, were not great engineers; possibly this was because of the contempt with which they regarded experimental investigations, or it may have been because as a race they were unattracted by the mechanical aspects of life. They were cunning artificers. We could realise that, even if we had none of their works of art to serve as a guide, by the account that Homer gives us of the wonderful craftsmanship of Achilles' shield; and I cannot help thinking that there was something of the engineer in Homer, for he describes the building of Odysseus' boat fondly and appreciatively; but otherwise, except in architecture, the Greeks left behind them nothing really notable in the way of an engineering feat.

With the Romans it was different. They, if you will, were engineers of no mean order of skill. They built roads that have lasted throughout the ages; they constructed aqueducts to bring water to their cities; they drove tunnels through the living rock, having learnt how to soften the rock face at times by burning it, and at times by pouring vinegar on to the heated surface; they were skilled miners, having learnt this art, perhaps, from the

Phœnicians; and that they had born in them the spirit of the engineer is surely shown by the way in which they improvised a navy when they needed one to fight the Carthaginians. As bridge-builders, their skill was unrivalled, and it was a skill that was to be found not only among professional engineers, but among their generals, as those of us who have struggled through the famous account of how Cæsar built his bridge across the Rhine have doubtless appreciated with no little bitterness of spirit.

What an amazing thing it was that neither the Greeks nor the Romans ever reached the modern conception of science! The Romans must again and again, without knowing it, have conducted scientific experiments, but the idea never seems to have struck them that experiment must be the basis of all true knowledge. There must, I think, have been exceptions to this sweeping condemnation of the ancients. It is inconceivable to me, at any rate, that men such as Archimedes, to whom, by the way, it is conventional to credit the invention of the screw, should not have deliberately planned experiments. There is no reason, so far as I know, to doubt the story that he succeeded in focusing the rays of the sun on to the mooring ropes of an enemy's fleet and set them afire, and it is impossible to believe that he could have had the knowledge necessary for this feat, or the many others attributed to him, unless he had gained it by experiment. But such men as he were isolated units. No one can accuse Lucretius of having planned an experiment, let alone of having made one, and yet, like the other philosophers, he based a whole system of natural philosophy on first principles evolved from his brain!

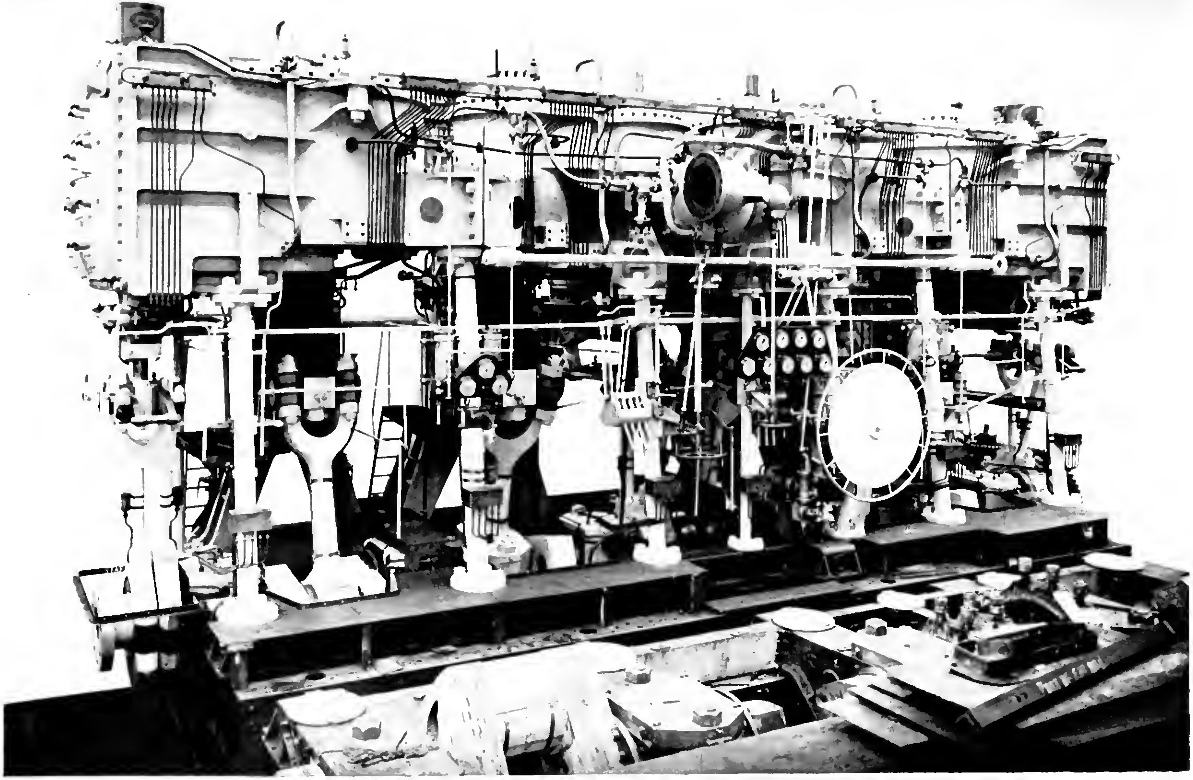
From the great days of Rome, we can pass at a stride to the early years of the seventeenth century. Gilbert, it is true, had written a book, "De Magnete," that was destined in a way to form the basis of electrical development; but men had added little to the traditions of engineering skill the Romans left behind them. Then came the results of the marvellous Elizabethan era, and Bacon crystallised out for the world the principles of inductive logic that turned men's minds from the barren syllogisms and speculations of the schoolmen—as the followers of Aristotle were called—to question Nature herself. Men became curious about all manner of subjects. They met together in a spirit of scientific curiosity, and at last the Royal Society was born, a body formed to find out accurately what was known, and to add to knowledge by making experiments.

It is possible, I think, to assign two chief causes for this development; the first, unquestionably, was the invention of printing, by which it became easy cheaply to disseminate knowledge, and the other the researches of the alchemists and astrologers. Both of these classes of investigators were forced to observe closely, and the alchemists, at any rate, were obliged, in their researches after transmutation and the philosopher's stone, to conduct experiments. In any case, no matter what the cause, the publication of Bacon's book, the "Novum Organum," marks the commencement of the new era in science. Since Bacon, there has only been the development of a single new idea, and even that, if we look closely enough, is contained in Bacon's work; it is the importance of accurate measurement. Experiment, observation and measurement constitute the triple founda-

tion on which science and engineering have been based. If you will, you can add a fourth—imagination.

It was a long while before the ideas of Bacon bore any practical fruit. The new philosophers had to straighten out the crude ideas that were current before they could give the practical men anything they could take hold of and adapt for everyday use. There was Franklin, for instance, experimenting with electricity to have his lightning conductors described as "devil's rods"; Newton, evolving his theory of gravitation, but so poor with it all that he had to appeal to the Royal Society to have his subscription remitted; Boyle, conducting researches on the pressures of gases; and it was not till about one hundred and fifty years after Bacon had set men on the right track, that the engineer could look to science to assist him in his work.

When the light came at last, it came with a flash; fortunately, too, just about the time when England had a dim glimmering of what it meant to her to find coal and iron together. And with the ideas of science rapidly crystallising out, men woke up to a realisation of the fact that the engineers were admitting them to a wealth of power based on coal and iron and steam. It was a wonderful find when they at last realised what a treasure-house of power they had tapped in coal, and they were able in this mysterious substance to draw upon the rays that the sun had been sending down on to their country in the far distant æons of the geological past, and not unnaturally, they set to work to spend it freely. It is only now, prodigals that we are, that we are beginning to ask ourselves what we shall do when we come to the end of our



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THE ENGINE OF THE NINETEENTH CENTURY

Section of triple expansion engine as installed in battleships

capital, how we shall replace it, whether we have a right to use up in these generations a treasure to which we have no more claim than our ancestors and our descendants. The steam-engine arrived; the canal reached the height of its prosperity, to be ousted in part, at any rate, by the locomotive with the rails that made it possible. And still science was steadily working away perfecting its chemistry, its knowledge of elements and compounds, groping after the fundamental phenomena of electricity, concerning itself with abstract problems, such as the nature of heat, and all the time laying the foundation on which the engineer was destined to build. Meanwhile, the engineer was working out the manufacture of steel and was applying it to all sorts and kinds of machinery, thereby vastly increasing the productivity of the individual worker, and adding to the wealth of the land, not without arousing the furious antagonism of the handicraftsmen displaced. Slowly the steam locomotive developed, and little more than a hundred years ago, after having conquered on land, it gained an even greater victory on sea. A revolution was started in ship-building, to be followed by a still more stupendous change when ships were built of steel instead of wood. And, electricity was creeping in, indicating in no way at the outset the developments that were to be. The telegraph lines were laid, first overland and then under water—a triumph so great, that to the present day several people, with no justification, refuse to believe as regards the first Atlantic cable that any message but the first ever went across the wires; and in the 'fifties men made the great discovery that the various forms of energy could be expressed in terms of each other,

and could be converted the one into the other. How the world has leapt ahead since those days. Electricity, revolting like Jove against his father, Saturn, now threatens to oust steam, at any rate, as a direct motive power, from the field. The engineers with their modern appliances have developed the internal combustion engine where the explosive mixture of air and gas exercises a direct drive on the piston. Coal has been forced to give up its gas, and this, too, has been used as a direct source of power. With the vast forces at our command, we have not hesitated to build mighty vessels, to attempt great feats that our ancestors would have found beyond their strength. We are starting to harness the great waterfalls, and are pressing them into our service. We have not hesitated to sever the two Americas, calling again on another branch of science —medicine—to make it possible. We have thrown great dams across the rivers and brought prosperity to countries that we found overburdened with debt. We have set lights in the midst of the sea to guide our vessels safely to port. We have thrown bridges over chasms and over straits where formerly men had to be content to make long journeys to pass round. Even the Alps have been pierced by our tunnels. The world has been linked into a conglomerate whole by the railways and the telegraphs that we have laid across its surface. We have rescued our sunken treasures from the deep, brought waters to our cities from vast distances, or carried our pipes over miles of dry and thirsty deserts. We have attempted and are on the way to achieve the very conquest of the air itself. These are but a few of the feats of which our engineers can boast, and they look forward to still greater triumphs. Let me quote to you what

an enthusiastic American, Mr. Herbert N. Casson, has to say of one aspect of the future in *Munsey's Magazine*. With pardonable zeal, he writes of the achievement as if it were American, and America has, indeed, made her contributions of moment to the history of engineering.

" This," he states, " is the day of big units. One freight-car carries forty tons. One Erie canal-boat carries a hundred thousand bushels of wheat. One grain ship on the Great Lakes carries two hundred and fifty thousand bushels. One train carries the grain that was grown on six thousand acres. One grain elevator holds six million bushels. One flour-mill at Minneapolis fills seventeen thousand barrels with flour in a single twenty-four-hour day. One single steel girder in the Woolworth Building in New York was so heavy that sixteen horses were required to haul it from the freight yard. One single copper mine—the Red Jacket—has engines of eight thousand horse-power, which hoist ten-ton cars of ore to the surface of the ground in ninety seconds from five thousand feet below. One single iron-ore steamer—the *Augustus B. Wolvin*—loads ten thousand tons in eighty-nine minutes, and unloads them in four hours. One single passenger steamship—the *Lusitania*, or *Mauretania*—hurls herself through the waters of the Atlantic with the power of seventy thousand horses. This is the day of tonnage. The average American iron and steel plant in 1870 produced a little more than four thousand tons; in 1913 the average plant will produce about sixty thousand tons. The output of Pittsburg alone is equal, in tonnage, to a Great Pyramid every four weeks. It means in just a single year thirty-five thousand trains of cars, fifty cars to a train, fifty tons to a car. Ninety million tons a year.

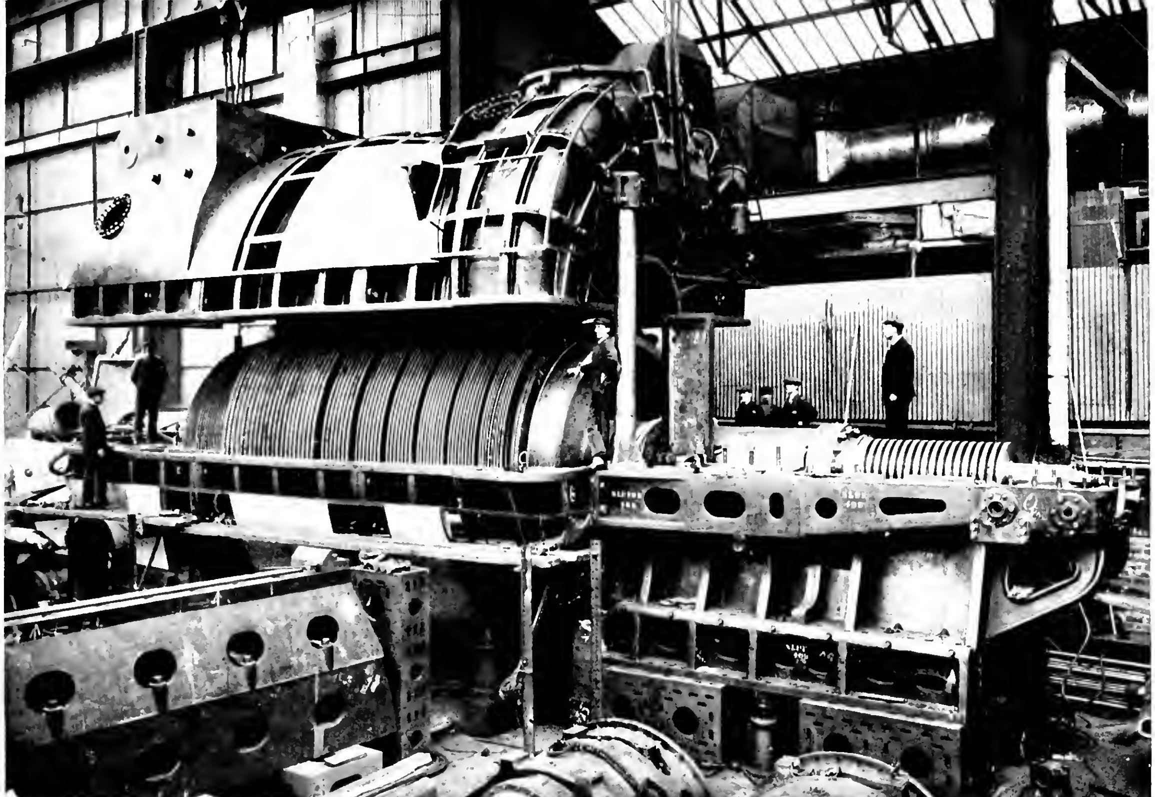
All the horses and mules in the United States could not budge the annual tonnage of Pittsburg.

"One single American company—the United States Steel Corporation—smelts in one year twenty-five million tons of iron ore; and it handles this stupendous output from ore-bed to finished product without the use of horses. If the iron and steel business were on a horse-power basis, steel rails would not sell for twenty-eight dollars a ton—less than one and one-half cents per pound.

"Talk about tonnage! So vast have our American industrial enterprises become that the total freight now carried by rail and ship is fully two billion tons a year."

Or you may look at the matter differently and consider the chief underlying aims of modern engineering to be to enable a man to be in different places at one and the same time, and to transport him from place to place with the minimum expenditure of time. Consider the telegraph and telephone, for instance! The personality of a single man can be exerted in a single hour in every business centre of the world if he has the service of the telephone and cable companies. The Press, with its vast collecting and distributing agencies, endorses the view that the essence of our engineer-built civilisation is the immediate and universal distribution of news, the annihilation, in fact, of space and time. Primitive man, by his weapons, by his sling and his arrow, groping at this idea, made possible his ascent from the brute. Civilised man, carrying the process farther, has attained an eminence and a dominance over Nature that would have been unthinkable to any age save that in which we live.

Great Britain need grudge no other nation a fair recog-



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THE ENGINE OF THE TWENTIETH CENTURY

One of the turbines for the "Aquitania." The case is being lowered into position

nition of their achievements. In the following pages, you will read of the exploits of some of our great engineers, and of the mighty feats they have carried through all over the world. We can be proud of our engineers, and of what they have done. They have led the world since the days when the art of engineering revived, and, for my part, I am confident that the work we still have to do in the world is not yet accomplished. If, however, we are to retain our pride of place, it can only be by merit, by doing the work that lies to our hand honestly as good craftsmen and as good artists, and by showing that same enterprise in the future that our ancestors showed in the past, when by their deeds they raised England and the Empire to the premier place among the powers.

CHAPTER II

THE PANAMA CANAL

Few great undertakings become familiar in our mouths as household words unless they appeal to our imagination both by their grandiose conception and by their intrinsic importance. The fame of the Panama Canal as a colossal undertaking has been a matter of common knowledge for over thirty years, and by the time the lines that I am writing now appear in print it seems likely that the world will have learnt that their three-century-old dream has materialised as a fact, and that the great ships will be passing to and fro on the narrow thread of water that now for the first time unites two mighty oceans. The achievement rightly fires the imagination. Rumours from the Canal Zone tell of the great forces used in rending the native earth; of the mighty engines toiling and groaning and clattering incessantly at their tasks; of the labourers swung across the vast cut 100 feet up in the air in cement buckets, taking this aerial pathway to their homes as unconcernedly as the suburbanite calls at the station for his train; of the gallant fight put up against accident, disease and the forces of Nature—all with the glamour of the tropics flung athwart the scene. So much for the one aspect of the work. The other is the saving in human effort that the completed Canal will for all time ensure. Ships now have a perilous passage to travel if they wish

to pass from the Atlantic to the Pacific, so much so that it has been said that no man is a seaman till he has thrice rounded the notorious Cape Horn, the southern limit of South America. Here are a few distances as they stand by to-day's route, and as they will be when this book is in your hand:

	Via Cape Horn	*Via Panama*
New York to San Francisco ..	13,107 miles	5,294 miles
New York to Peru	9,700 ,,	3,359 ,,
New York to Auckland ..	11,771 ,,	8,610 ,,
New York to Sydney	13,051 ,,	9,709 ,,

Or take another table. Panama is the centre of the Pacific coast. Let us consider the distance it is from the chief ports of the world to Panama, first via Cape Horn and then via the Canal. They are as follows:

To Panama from	*Via Cape Horn*	*Via the Canal*	*Saving by Canal*
Antwerp	11,383 miles	4,463 miles	6,920 miles
Charleston ..	10,803 ,,	1,611 ,,	9,192 ,,
Galveston	11,391 ,,	1,545 ,,	9,846 ,,
Genoa	11,143 ,,	5,229 ,,	5,914 ,,
Hamburg	11,614 ,,	5,054 ,,	6,560 ,,
Havana	10,682 ,,	1,425 ,,	9,257 ,,
Havre	11,156 ,,	4,648 ,,	6,508 ,,
Liverpool	11,261 ,,	4,575 ,,	6,686 ,,
Marseilles	10,985 ,,	5,071 ,,	5,914 ,,
New Orleans ..	10,286 ,,	1,425 ,,	8,861 ,,
New York ..	10,851 ,,	2,017 ,,	8,834 ,,
Southampton ..	11,137 ,,	4,608 ,,	6,529 ,,

With these figures before you, you will not find it difficult to believe that the building of the Panama Canal is the greatest engineering achievement of the world. The

idea of severing the two Americas by driving a waterway straight from the shores of the Atlantic to those of the Pacific has appealed to the imagination of man since the day that it was proposed in 1520—some thirty years after the existence of the New World became known to the Old. For over three centuries the project remained a dream, the idle fancy of the visionary, and it was not till the nineteenth century—the century above all its predecessors of practical achievement—that a serious survey was made to consider whether the undertaking might not be feasible. To the Frenchman, Ferdinand de Lesseps, who triumphantly severed the isthmus joining Africa and Asia by the Suez Canal, but who died a broken-hearted man when catastrophe overtook his operations at Panama, belongs the credit of having converted the world to a belief in the possibility of the scheme. The problem was a stupendous one. From deep water to deep water the distance through which the monster ditch has had to be dug is 50 miles—more than twice the distance it is from Dover to Calais. On either side, the mean sea-level is the same; but while the Atlantic Ocean has a lazily rising tide that swings through a bare range of 2 feet, the high level of the Pacific towers 20 feet above its low level. The land at Panama is rocky and mountainous. A section of the route shows how the hills to be traversed rise over 300 feet above the level of the sea; but any sketch is silent as to the fact that the work has all to be done with the broiling heat of a tropical sun beating down on the workmen, and it tells nothing of malaria or of the dreaded yellow fever, the terror of merchantman, man-of-war and buccaneer, that swept away the labourers and the engineers who tried to carry

out the designs of the inspired Frenchman, the great de Lesseps.

Of the different routes proposed, of the controversies, of the financial difficulties, of the startling way in which the Republic of Panama carried out a bloodless revolution to secure the adoption of the route running through their country, and of the earlier attempts I have no space to write. Of the many dramatic incidents that heralded the birth of the Canal, none is more so than the fact that this great undertaking, designed to facilitate the peaceful flow of commerce, was finally decided on by the needs of war. In the spring of 1890 war broke out between the United States and Spain. At the time, the battleship *Oregon*, perhaps the finest in the United States Navy, was at San Francisco, and in order to get to the scene of operations, she had to undertake the long and perilous journey of 13,400 miles round Cape Horn, instead of the 4,600 miles that would have been necessary had the Canal been open. The incident struck popular American sentiment, and at once the people of the States clamoured that their Government should undertake the building of the Canal.

Many troubles had to be surmounted, and then there was a long-sustained, wearisome debate as to the type of canal that should be built. The obvious policy was to cut a canal down to the level of the sea, guarded with great locks at either end owing to the changing levels of the water, but this would have involved an enormously greater amount of excavation than even the present Canal has necessitated; and at last the scheme was adopted whereby the ships coming in from the sea are drawn into great locks, raised as they lie between the lock gates 85 feet, and

then, having passed between the gorges of the land, are lowered back to the sea level of the opposite ocean.

The Canal as a Whole

To appreciate the work, it will be best to take a bird's-eye view of the Canal. Roughly, it runs south-east from Limon Bay to the Bay of Panama. The entrance is guarded by a great breakwater nearly 2 miles long, and the first 6¾ miles of the Canal are at sea-level. Then the Gatun locks and dam are reached. These are three twin locks, which lift the war vessel, the liner or the tramp 85 feet on to the level of the vast lake that has been formed by damming up the river Chagres. To Mile 39, the Canal runs along at this level, passing through the hills until it reaches the Pedro Miguel locks and dams. Here the boat is lowered to the level of the next great lake, the Miraflores Lake, formed by impounding the waters of three rivers, and to be kept at a level of 55 feet. At Mile 41 the Miraflores locks are reached, and the boat is there lowered to the level of the Pacific Ocean; and at Mile 50, the dredged passage which has been driven through the Bay of Panama ends in the deep water of the Pacific, and the ship is free once again to proceed on her business to the uttermost ends of the earth.

The Excavations

Let us turn from the accomplished fact to consider the work achieved. By the time that the last shovelful of earth and rock has been removed, no fewer than 200,000,000 cubic yards will have been excavated. I have been trying to realise what this vast mass of earth means, and perhaps the clearest way will be to consider what we could do with

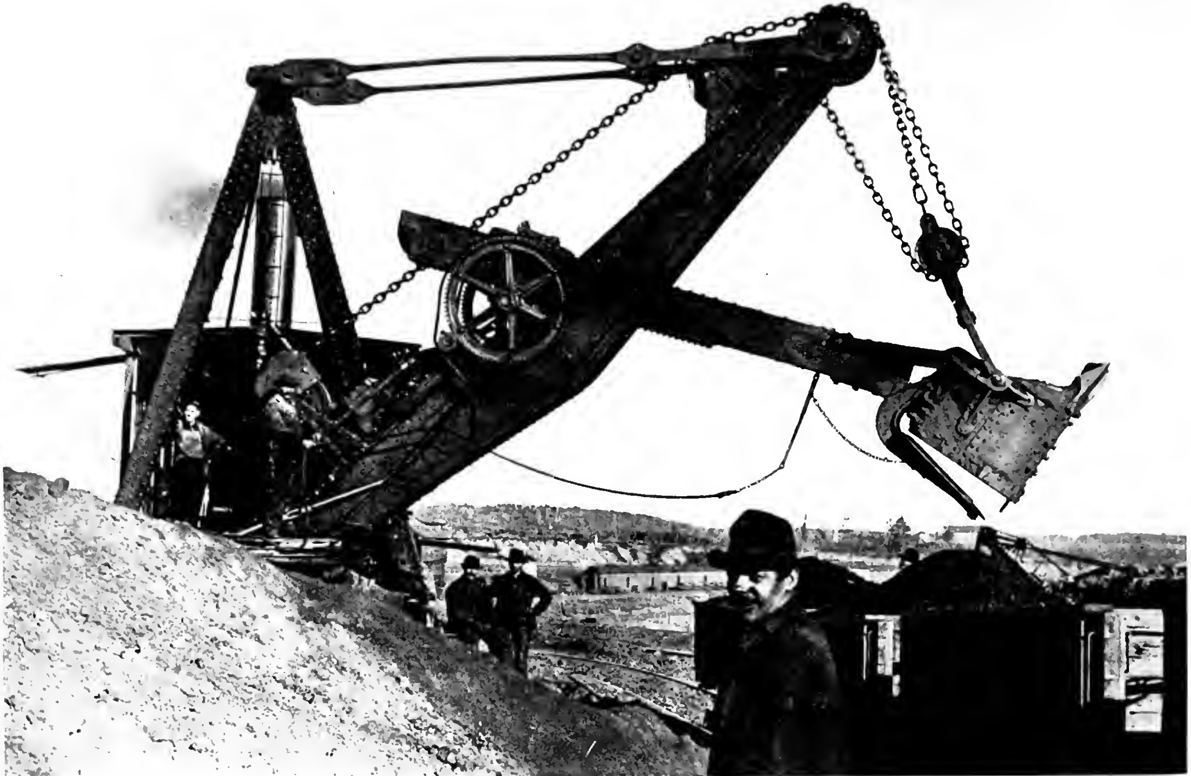


Photo: Underwood & Underwood, London

GIGANTIC STEAM SHOVEL DUMPING A FIVE TON LOAD INTO A CAR

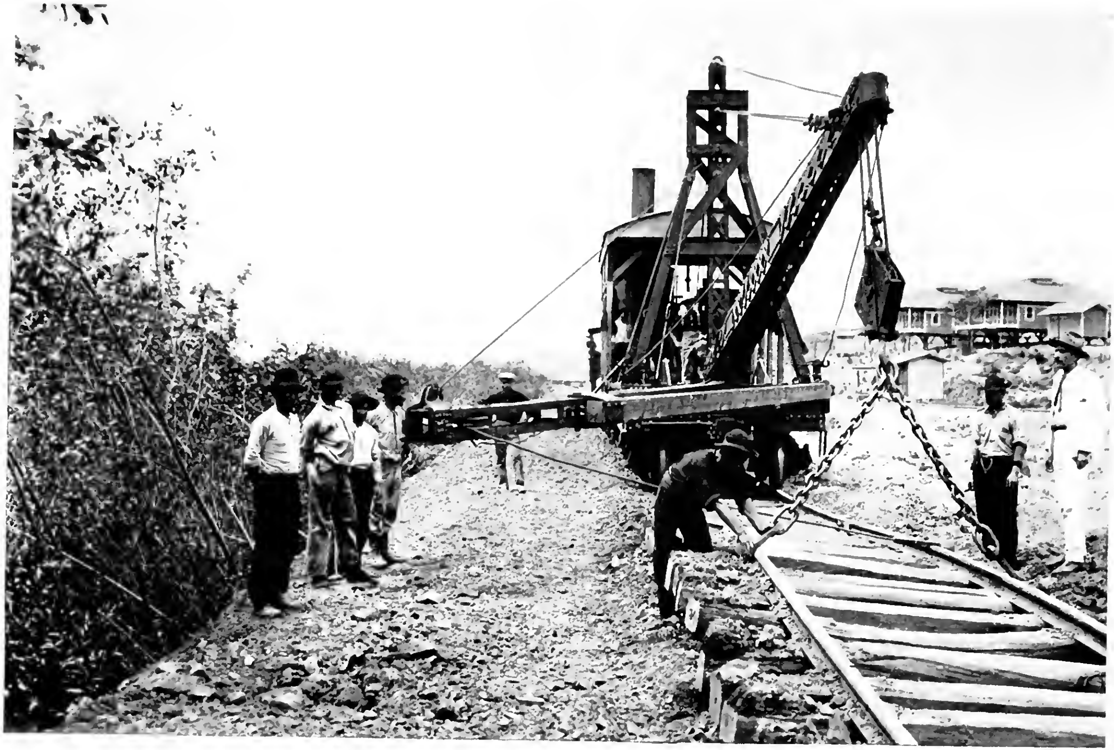
such a volume of earth. Supposing that we used it to pave a causeway round the world; we could build the causeway 1 yard high and 4½ yards wide. Or let us take the most recent estimate of the world's ships of over 100 tons burden. The quantity of earth excavated would weigh in the aggregate about eight times the total of ships owned by all the nations. All the many resources of the engineers have been brought into play to deal with this stupendous quantity of material. Twenty dredgers have been in use, some of them scooping up the mud in their great buckets, others sucking it up with pipes, but the bulk of the work has been done by the monster steam "navvies," or shovels. Here is the list of the apparatus in use at the time of writing for the dry excavation:

Locomotives from 117 tons downwards ..	315
Steam shovels up to 105 tons	98
Wagons and miscellaneous cars	4,339
Lidgerwood ploughs	30
Spreaders	25
Track shifters	10
Pile drivers	19
Churn drills	265
Tripod drills	295
Cranes	57

The steam navvy is a familiar sight in excavation work. As the accompanying photograph shows, it consists essentially of a crane and a large scoop that tears its way into the side of a cliff or pounces on the level soil, and then carries its load of stone and rubble and earth into one of the wagons to be carted away. You may have seen the steam navvy at work on a railway cutting in England, but,

even so, it only gives you a poor idea of these engines as they were in use at Panama. The Kinemacolor Company, with their usual resource, however, have brought before the English public the romance of the Canal building. London audiences have watched the scene amazed. There are the steam navvies, with their shovels swinging in the air, opening and closing like the ravening beak of some prehistoric monster bird, pouncing on their horrid meal of mud and stones, and disgorging it into the trucks; there again are the dredges, diving with their swinging beams, bringing up their load of rubble with the water pouring out in spurts. The world has had brought before it the high pressure hoses, through which the water hurls itself at the rock face, penetrating the cavities, loosening the soil in every crack, and bringing the cliff face down crashing in ruins to its foot. It is a stirring picture of the resource of man pitted against the resistant inertia of Nature. And all this fuss and bustle and turmoil spells energy triumphant. During the construction of the Canal, the record day's work for a steam shovel has reached the amazing total of 4,823 cubic yards.

One of the chief problems before the engineer has been to get rid of the mass of excavated material, otherwise he would have been "snowed under" by his own exertions. The rubbish has been dumped by being tipped into the outside skin of the various dams, into swamps for purposes of reclamation, or into the breakwaters at Colon and Panama. The track-lifter, again, is one of the many curious and ingenious machines pressed into service. Tipping, it is obvious, can only be carried on by continually moving the line of track, and placing it on the bank just formed



A TRACK-SHIFTER AT WORK

by the rubbish that has been shot out. The track-shifter consists, as the illustration shows, of a car, on the front end of which is a rigid **A**-frame with a swinging mast. A swing boom projects 30 feet from the car, and this carries tackle so arranged that the rails can be grabbed by two pairs of powerful tongs. When it is desired to shift the rails, the track-lifter starts from the free end of the rails, grabs them and their ties, lifts them clear of the ground, and shifts them 2½ or 3 feet to the side, where they rest on the ground that has just been dumped there. The track-lifter then moves back and throws another section. This makes fairly easy reading, but it must be remembered that much of the excavating work has been done in rock that is too hard for the steam shovels to work in. To surmount this difficulty, a high pressure water-hose, as I have described, and drills have been employed. Holes are drilled into the rock about 24 feet deep. A small charge of dynamite is then exploded at the bottom of each hole to enlarge it. This is followed with a charge of between 70 lbs. and 200 lbs. of dynamite, and this, on being exploded, cracks up and loosens the rock sufficiently for the steam shovel to be able to seize and carry it away. On an average, the enormous quantity of about 500,000 lbs. of dynamite have been used in a month.

Mr. W. H. Foster, in the course of an able article he wrote in *Scribner's Magazine*, describes the care with which the dynamite has to be handled, premature explosions having on more than one occasion occurred. He writes: " 'Seeing the sights?' piped the hulk of a man in an unexpectedly squeaky voice. 'Well, you'll see one in a minute. Just going to lift about 75,000 cubic yards off

the top of that hill back there. Accidents? Well, yes, one or two. That's Bas Obisbo. Put twenty-six men into clear there at one shot, and winged some sixty more.' His left hand involuntarily went to his empty right sleeve, and I knew that he had a vivid recollection of the disaster. 'Never knew what fired it,' he said. 'Some thought it was a high-temperature layer of limestone about 30 feet down. Some said short circuit. All I know is that she blew about four hours too soon, and 'twas something wicked. Now, dynamite is very weird stuff,' he continued. 'You don't know just what it will do, and we have accidents right along; can't seem to help it. The more I know about dynamite, the more I find I don't know. The worst scare I ever got, though, outside of being blown up myself, was when the President came through here on an inspection car. Orders had been given to have all switches spiked, all loaded holes fired, and no more to be loaded. All powder was to be put back in the magazines and locked up. All was fine as frog's hair as far as Empire, when I happened to look up, and there was a fool nigger sliding down into the cut right in front of the car with a 50-pound box of dynamite on his head. He didn't even know where he got it, but any way he dropped it. Well, sir, I expected to see that inspection car and the high and mighties and the President of the United States just disappear; but they didn't. I've known dynamite to go off, though, with less excuse than that had. These steam shovels are great things, aren't they?' he asked, after a lengthy scanning up and down the animated lines of operation between the walls of greenish-grey stone and red gravel. 'Just like big, patient elephants,' he went on, 'they do just whatever the

puny little man tells 'em to. Let's go over and see " Baldy." He's the best shovel engineer on the job when he's sober.' We made our way over the pilot-cut and neared ' Baldy's ' shovel, which was groaning under the weight of a 20-ton boulder. This it laid on a car with motherly care, and, with a final caress, swung back to look, in a near-sighted way, for another dipperful."

An aspect of the excavation work that has continually hampered the engineers has been the frequent occurrence of slides and slips in the excavated Canal. The slides are of two kinds. One is due to soft material sliding over on the harder material below, and the other kind occurs when a soft layer underneath is squeezed up by the weight of the sides. The latter of these you can reproduce for yourself by taking two boards and placing them close together on wet, clayey soil. When you stand on the boards, the mud oozes up owing to the pressure of your weight between the boards. The importance of the slides can be appreciated from the statement that up to the end of 1911, over 9,000,000 cubic yards of extra excavation had to be made on account of them.

I could write much more of the difficulties met with and the ingenuity exercised in excavation work, but we must pass on to consider the great dams, leaving the statement to speak for itself, that the record movement of trains in connection with the Culebra cut alone (you can identify the cut on the plan) occurred on March 11, 1911, when 333 loaded trains left the cutting, representing 79,484 cubic yards of excavation. The handling of this great volume of traffic over roughly-laid lines was in itself a triumph of organisation.

The Dams

There is something awe-inspiring about the five great dams which, by keeping the water under strict control, have made the construction of the Panama Canal possible. There are one at Gatun, two at Pedro Miguel, and two at the Miraflores locks. The Gatun dam is the largest of the five. It is 750 feet long, it rises 115 feet above sea-level, is 2,100 feet wide at the bottom, 400 feet wide at high water level, has a volume of 21,000,000 cubic yards, and forms a lake about the size of Rutland, being 104,960 acres in area, and containing 206,000,000,000 cubic feet of water. When you consider the torrential rainfall of the district, it is possible to form a conception of the titanic forces that have to be controlled. The Chagres River that is held up by this great barrage can become a raging torrent, that from back beyond the dawn of history has been sweeping every obstacle before it down to the sea. On one recorded occasion it has risen 40 feet (the height of a large house) in 24 hours, a fact not to be wondered at when it is remembered that the maximum rainfalls recorded are, for three minutes, 2·46 inches; for an hour, 5·86 inches; and for 24 hours, 10·86 inches. When 6 inches of rain fell in parts of Norfolk last year in 24 hours the whole district was flooded out. To deal with these great forces, the strength of construction has had to be enormous. The method employed has been to build two great outside walls of concrete, rock and such-like material, and to fill the space between these with matter of a silty nature pumped from the bed of the Chagres River. At the beginning of 1912, water was allowed to rise in the lake that was formed by

such a barrage across the hills, and on February 18th of that year the old Panama Railway became submerged, and a portion of the Canal began to take definite shape. Obviously, it is necessary to allow an outlet for the waters of the great lake, and for this a special channel, named with characteristic technical genius as the Spillway, faced with cement, has been cut 300 feet wide and 1,200 feet long, to conduct the overflow at the rate, if need be, of 154,000 cubic feet a second back into the old bed of the Chagres River. Sluice gates controlled by electrical power derived from turbines are installed to regulate the quantity of water in the lake, and as an indication of the completeness with which the river has been tamed, it is estimated that even if the sluice gates were closed the heaviest rainfall known would only raise the waters of the lake by 1 foot in 9 hours. Of the other dams, which are similar, but smaller, there is no need to write.

The Locks

The locks of the Canal and the work they are called upon to do must stir the imagination of the dullest minds. Conceive, if you can, of any crane that could pick up a mammoth liner and raise it 85 feet, and then remember that this is the work that the locks of the Panama Canal will be doing day by day from the time that the works are open to traffic. The locks in all cases are in duplicate, so that one may be used for eastward-bound and the other for westward-bound traffic. Each is 1,000 feet long and 110 feet wide. Tunnels in the side walls of the locks and in the central partition that divides them allow for the inflow and outflow of the water on which the ships will be

raised and lowered, and the locks have been designed for the lifting to proceed at the rate of 2 feet a minute. The gates are in essence the same as all lock gates, and are constructed on the principle that has been known from before the days of Solomon, so that the pressure of water on their faces brings them the more closely together, making them present a V-shaped surface to the force of the water. The most interesting features of the locks at Panama are the elaborate devices for protecting them from injury, either by ships colliding with the gates or other accident that would open through communication between the high and low-level waters. The bursting of dams has been notorious as a cause of disaster throughout history, and to prevent such an international catastrophe as the wreckage of the Canal there are five special devices. Firstly, the centre wall of the locks is produced 1,000 feet beyond the lock gates on either side, and all ships will be compelled to stop at this wall and moor before entering the locks. Secondly, vessels are to be towed into the locks by electric locomotives instead of proceeding in under their own steam. Thirdly, outside the lock gates a great chain is stretched that lies ordinarily at the lock bottom. If there is reason to fear a collision between the lock gates and a vessel, the chain can be raised by hydraulic cylinders in the walls, so as to stretch across the lock entrance on a level with the coping, and it is calculated that by this means an almost unthinkable force could be absorbed, so that a 10,000-ton vessel moving at 4 miles an hour would be brought to a stop in 70 feet. Fourthly, each lock is provided with double gates, so that if one pair is injured the other will be able to keep back the head of water ; and,

lastly, a special form of bridge has been designed as a further line of defence to act as a temporary dam. The heart of the locks lies in the central mass that divides each of the twin pairs. About 81 feet high and 60 feet thick, it is built solid for a little more than half its height, when the base divides into two retaining walls. These are partly filled in with earth, but also contain the tunnel, in which the lock works are safely concealed. This tunnel is divided into three parts, the lower portion of it being used for drainage, the centre for the electric cables for supplying light and power to work the gates and valves, and the top portion as a passage to enable men to reach and work the machinery.

The Difficulties of Organisation

The work of excavation, the great dams and the locks are the chief engineering features of the Canal, and the utmost credit is due to the United States for the way in which their organisation has triumphed over difficulties. When the French attempted the building of the Canal, among their greatest difficulties was disease, that too often resulted in death. Malaria and yellow fever claimed their victims by the hundred, and it is to the enlightened methods and self-sacrificing devotion of the pioneers in modern medicine that the success of the engineers is in no small measure due. Once it was learnt that the mosquito was the carrier of malaria and yellow fever, swamps were drained, precautions were taken, and disease vanished.

Apart from the question of health, the problem has demanded first-rate genius for organisation, a genius that the engineer is always forced to have at his command, but

which has assumed in this great undertaking unparalleled dimensions. There has been a standing labour force of 35,000 men, which, with their dependants, amounts to a population of 65,000. The material and supply branch has had eight huge general stores. Hotels and restaurants have been run up in the supply zone, and every day a special train of twenty-one cars has worked across the lines with perishable foods. The whole settlement has been organised and managed automatically, and even paternally, by the Canal authorities, and as a result of their wise governance efficiency has resulted. In a paper that Colonel George W. Goethals, the chairman and chief engineer of the Isthmus Canal Commission, read to the British Association when it visited Winnipeg in 1909, he summarised the work, with the modesty characteristic of a great man, in the following words:

"No new engineering problems have arisen, and none are likely to come up. The difficulties are due entirely to the magnitude of the work, complicated by conditions resulting from delays in securing supplies, the effects of the climate, and the contentment of employees, rarely encountered elsewhere, but which have a material bearing on the issue. Results are obtained not alone because of the machines in use, but by the organisation, which is formed of upwards of 30,000 men of all walks of life, and of practically every nationality. Authority is centralised, but responsibilities are distributed from the various heads of departments on down to the lowest in the ranks. Each man has a task to perform, each knows the results desired; it is his duty to secure them, the necessary discretion being allowed to secure brain effort as well as brawn. Competition spurs men on to effort, and in carrying on the work this

factor is not forgotten. As a consequence, the organisation is itself a huge machine, which, in an enervating climate, and notwithstanding the human element, has made not only the steam-shovel produce results never before anticipated, but can carry to successful completion, if provided with the necessary means and protected against disease, the greatest work that has ever been attempted."

The Canal, as I write, is now nearing completion, but before we leave it, let us take a glance at one of those unimportant aspects of the work that help our imagination to grasp the greatness of the enterprise. The *Canal Record*, shortly after the waters had been let into the excavations, drew attention to a curious phenomenon frequently seen on the Panama Canal. At times, the Gatun Lake has not a speck of any kind on its surface, except for an occasional white-capped wavelet; an hour later, the surface is seen to be dotted with small green islets. These small "floating islands," as they are called, are masses of vegetation and earth loosened from the bottom of the Gatun Lake; they have been found on examination to consist mainly of sticks and leaves held together by clay, with grass and other vegetation growing upon them. Though they have been found as large as three acres in extent on Lake Gatun, they are no obstacle to a steamer, though they would impede a launch, and they are firm enough for a man to walk upon them safely. The sudden appearance of the islets is caused by the change of wind; they have previously been driven against the trees on the south side of the anchorage basin at Gatun by the wind blowing up the Chagres valley, as it commonly does; then, if there is a lull in the breeze or a change of direction, the islets drift out into the lake.

For the purposes of comparison, the following table, giving the data of some of the chief canals of the world, may be of interest :

OTHER EXISTING CANALS

Canal	*Places connected*	*Date of construction*	*Length in miles*	*Breadth in feet*	*Depth in feet*	*Cost in £*
Panama ..	Atlantic and Pacific.. ..	1879–1913	50	300–500	41	£80,000,000 estimated
Suez (original)..	Mediterranean and Red Seas	1860–9	104–8	196–328	25	£18,000,000
,, (present)..	Do. do. ..	1895	104–8	420	31	£2,500,000 additional
Kiel	Baltic and North Seas ..	1887–95	61	72 *at bottom*	29.5	£19,000,000
Amsterdam ..	Amsterdam and North Sea ..	1865–76	15.5	164	27.9	£3,000,000
Manchester Ship	Manchester and Atlantic ..	1887–94	35.5	175–230	26	£15,000,000
Corinth	Gulf of Corinth and Algeria ..	1884–93	4	80¼	26¼	£1,000,000
St. Mary's Falls	Lakes Superior and Huron	1853–5 and 1904	1	160	25	£1,200,000
		1888–95	1½	150	22	£800,000

CHAPTER III

HARNESSING THE NILE—THE GREAT DAMS AT ASSOUAN AND ELSEWHERE, AND WHAT THEY HAVE MEANT TO EGYPT

FIRE, the old proverb says, is the best servant a man can have, but it is the worst master. Had the wise men of old had the knowledge that we have to-day of mechanical achievement, I think that for fire they would have substituted water. Terror rides athwart the eddying smoke of a prairie fire; it is in all its awesome majesty when the houses of a city burn and the red flames destroy the life of a people; but is the horror of triumphing fire equal to the horror of triumphing water, and can the services that fire renders stand comparison by those of water? Man's mastery over water is one of his oldest arts, but it is only to-day that he is realising what water will do for him if he asks it. The old world knew the use of irrigation; agriculture, in fact, started on an irrigation basis, and the literature of the East is full of references to the beauties of well-watered gardens, and to the blessing of water to a dry and thirsty land. It knew, too, that the natural falls could be pressed into service to drive water wheels, and so to grind corn for man, and to assist him at the birth of manufacture. It had learnt that water was the great carrier, whether the waters of the ocean, the waters of the rivers, the waters of the tidal estuaries, where the river ebbs and flows with the pulsing of the sea, and the waters, too, of

the canals. But the engineer to-day realises that it is only now, after centuries of effort, that we are inviting these agencies to exert for us a tithe of their full powers. We are harnessing the great falls and using them to generate electricity that is to light our cities and to turn for us the wheels of our factories in far remote places; we are using the force of falling water to fertilise our lands, and give to the fields the nitrates that enrich the crops; in all parts of the earth we are carrying out irrigation works with mighty barrages that are bringing into cultivation great areas of land that till now have been arid wastes, and that are saving our herds of cattle and sheep from the dread terror of drought. And, as yet, the work is only at its beginning. That you may realise what we are doing, I am asking you to think of the following true story, as analogous with the uses we are now making of water as compared with the uses that were made of it by the ancients. I am indebted to the kindness of the editor of *Technical World Magazine*, where it first appeared, for permission to reproduce its substance.

Recently, an American mining engineer was looking over some abandoned gold smelters at Mazapil, an old Mexican town buried in the mountains. When he returned to civilisation, he carried with him several bricks from the buildings of Mazapil, and some samples of slag which he turned over to the Company assayer. The mining engineer had suspected that, with the crude mining operations in vogue at the time of the former operations, there would have been some loss in extracting the gold from the ore, but he was hardly prepared for the assayer's report, stating that the bricks and slag ran nearly $500 to the ton, gold,

silver and copper. Further investigation has shown that the streets of Mazapil are literally paved with gold and silver, to say nothing of the high percentage of the baser metals—copper, lead and zinc. The Company sent its representatives, and is now in possession of all the old smelters and their huge slag piles, the garden and its wall, and nearly all the old buildings and pavements in the town—even including the post office !

The story of the town paved with gold makes a strong appeal to the imagination, but it is in essence nothing beside the vast irrigation and power works that the engineer of to-day is undertaking. Many great construction works might be chosen to illustrate the truth of this as regards irrigation. I shall content myself with a brief consideration of one, the harnessing of the river Nile, and, above all, the construction of the great Assouan barrage. I shall then refer to a few of the other irrigation schemes in the rest of the world.

Egypt is, and from the beginning of recorded history has been, the world's wonderland, and rightly the Nile has been spoken of as the Father of Egypt. To think properly of Egypt, you must imagine a rainless country dependent for its existence on the supplies of water that come down to it from the heart of Africa through the river Nile. One of the earliest Bible stories, the story of Joseph and the famine in Egypt, tells that in those distant years the Egyptians were faced with just the same problem that faced Napoleon when he took over the country, and that faced our Empire-builders when we were called upon to assume the responsibilities of occupation.

The source of the Nile stretches away to the southward,

far beyond the land of Egypt, and it falls down great cataracts on its way to the sea. The last of these mighty falls—known from the point of view of the river's mouth—is the "First Cataract" at Assouan, and is the site of the great barrage that has fired the imagination of the world, and has been constructed to keep back the waters in the times of flood, and to release them as they are required to fertilise the land.

Let us imagine ourselves passing up the Nile from seawards, and paying no attention to any but the larger barrages. We should travel up one of the two great branches by which the waters of the Nile reach to the Mediterranean. Between them lies the delta of the Nile, so called because of the resemblance of its shape to the Greek capital D (Δ), and as we began to get near Cairo, the site of the Pyramids and the region whence these two branches diverge, we should find ourselves having to pass through the locks of a large barrage that stretches across both branches of the stream. Next time you hear people tell of the vandalism of the engineer, speak to them of the history of this barrage. The idea of it originated in the mind of the great Napoleon, who saw that it was necessary to hold up the height of the river Nile, if the delta lying below was to be properly supplied with water. Mehemet Ali, the founder of the present Egyptian dynasty, after Napoleon's short occupation, set to work to carry out the scheme. He was a ruthless but far-seeing tyrant, and had already built the great Mahmoudieh Canal in a single year, forcing 250,000 labourers to leave their homes and excavate the canal without tools, using their bare hands to fill the baskets in which the excavated earth was carried

away. Twenty-five thousand of the labourers died at the task.

In describing the origin of the barrage, Mr. John Ward, in his vivid sketch of Egypt, under the title "Pyramids and Progress," speaks thus of the origin of the work: "Various French engineers were summoned to carry this out. One ventured to suggest a great stone embankment. 'Well, then,' said Mehemet Ali, 'you have those great useless heaps of stones, the Pyramids: use them up, every block, for the purpose.' The engineer knew that infamy would attach to his name if he agreed to this proposition, and asked some days to make calculations. His master would only allow him one day. When the engineer again appeared, he said the cost of transporting the stone from the Pyramids would be greater than to quarry it anew in the mountains. 'Then let the Pyramids stay, and quarry new stone,' said the tyrant, and so the monuments were saved."

The barrage was begun in 1837. In nothing more than in engineering is cheap work bad work. Forced to rely on unskilled labourers, obliged to hurry on the construction, the French engineer laid the foundations for his masonry on rubble and cement tumbled into the river, and it was not until 1861 that the barrage was completed. When, two years later, the attempt was made to hold up the stream with it, the barrage cracked, and began to move off bodily towards the Mediterranean!

To the great British engineers, trained in irrigation work in India, belongs the credit of having saved the barrage and rendered it efficient, and also to Lord Cromer, who had the strength of purpose to trust fully and to

support enthusiastically those in whom he had confidence. There was talk of blowing up the useless barrage, but Sir Colin Moncrieff and Sir William Willcocks undertook to save it at a cost of £500,000, the price that it would have cost to destroy. The work was one of extreme difficulty. When the Nile was low, sections of the bottom had to be isolated off by banking back the stream; that portion of the bottom had to be pumped dry, the bad parts of the embankment had to be strengthened and protected by plastering them with cement, and the weakened piers had to be underpinned. Men worked at the job night and day, the light to carry on the task at night being derived either from the moon, or when that failed, by electric light laid on to the bed of the stream. Mr. Ward, who saw the work when completed, and also the new work done later, when a further addition was made, describes it as a "beautiful light structure, with its slim towers and embattled gates, spanning the mighty Nile. There is no great engineering work at once so dignified, so useful, and so picturesque." As he points out, the restoration of the barrage, by raising the Nile level, doubled the agricultural produce of the Delta.

Much might be written of the Delta barrage, but let it suffice here to say that the capacity of the barrage to hold back the Nile was enormously increased by placing great weirs below it, so as to some extent to relieve the pressure, the water between the weir and the barrage obviously pressing against the north side of the barrage and resisting the force of the water above. By these means the barrage is now able to hold up 7 feet more water than was originally intended.

Photo by permission of Messrs. John Aird & Co.

BUILDING MATERIAL FOR THE NILE DAM

Stone-porters transporting a granite lintel weighing three tons

Here are some figures showing the effect of the work as illustrated by the number of acres of land in the Delta under cultivation :—

	Acres
Before British occupation..	600,000
Before the repair of the dam, the water being held up 6½ feet	1,200,000
Dam repaired, 1890	1,520,000
Dam improved by weirs, etc., 1898	1,700,000

Before passing on to the Assouan barrage, we will take this opportunity of considering the bare elements of irrigation. Water, we all know, finds the lowest level, and it is in obedience to the force of gravity that it runs downwards to the sea. It is clear, then, that in any district the river-bed will be the lowest part, the bed itself getting lower and lower as it nears the common level of the ocean. But the bed of a river often runs in shelves, a waterfall occurring at the edge of each shelf. This is usually due to the fact that the ground is of different kinds, some parts being harder, and some softer. The softer part gets eaten away, but the harder part resists the wearing action of the stream, and so a ledge is formed. There are two ways, then, by which irrigation can be carried out. Either the water can be raised by the labour of bullocks or of men above the general level, and then distributed, or it may be led from one of these ledges and passed to the lands at the lower level.

Let me describe what happens in an ordinary Indian garden, and you will see in miniature the method that has been used to save Egypt from bankruptcy, by increasing her sources of wealth.

A sloping mound leads to the well's mouth, and a large leather bucket tied to a rope runs over a pulley. Let us start with the bucket in the water. A couple of bullocks are harnessed to the rope and walk down the slope, dragging the bucket up from the well, being helped in their hard work by the fact that they are going down hill. The bucket comes to the surface and unloads itself in a tank, and as the bullocks return, the rope slackens again, and the bucket drops back to the well. From the well pipes or clay channels run to various parts of the garden. The water passes from the higher level of the tank to the plot that is to be watered, and the bare-footed gardener dams the main channel with a little piece of clay, breaks down the clay embankment that is at the side of the plot, and the water flows over it. When enough water has entered, he removes his first tiny dam, repairs the second, and the water passes on to irrigate another plot.

In Egypt the same process is adopted to some extent, but large canals and dykes take the place of the channels described. Sluice gates are substituted for the gardener's lumps of clay, and the barrages do much of the work of bullocks in the Indian garden. The construction of the great canals necessary in connection with the barrages, canals many of which carry a greater volume of water than our river Thames, has itself been a work of first-rate engineering importance.

From Cairo and the Delta barrage let us make our way up stream. We will pass the barrages at Assiout and Esneh and come straight to consider the Assouan dam. It lies 753 miles from the sea, at a spot that is full of the romance of history. Just above it, now submerged beneath the

waters, is the island of Philæ, with its beautiful statues and temples, once girt about with graceful palms, which, alas ! have succumbed before the advances of civilisation. The Egyptian Government, while doing all in their power to preserve the remains on Philæ, have made ample amends for the damage inevitable through immersion, by underpinning and strengthening the temples, and by thoroughly repairing several structures of great archæological interest in the neighbourhood. While we are standing under the heat of the Egyptian sun in the clear air of Egypt, looking at the great piles of masonry that constitute the dam, let us consider the task that the engineers had before them when they undertook to place their granite shackles on the river. The climate was one of the first difficulties. The heat of the noonday sun is such that after it has been shining on iron or stone, the material reaches a temperature at which it would scorch the skin or cook a lump of dough that was placed upon it. The dam had to be built 1¼ miles long, and it had to be constructed solid enough to keep back the vast pressure that the Nile can exert when in full flood. This is so enormous that now that the dam has been completed there is a force of over 300 tons pressing against the sluice gates. The effect of the dam is to create a mighty lake where before was a raging boiling torrent, a lake several times the size of Loch Lomond.

It is difficult to convey in writing the magnitude of the difficulties that faced the engineers. But try to picture to yourself 1¼ miles of raging floods that have come down from the melting snows of Abyssinia, tearing their way through the rocky gorges that form the mythical tomb of Osiris, hurling themselves seawards with a force that

would sweep downwards in their bed 4-ton masses of granite. The problem for the engineers was to build solidly beneath the torrent foundations that would stand the strain of keeping in check one of the mightiest rivers in the world. In giving our meed of praise to Sir William Willcocks, Lord Cromer, Sir Benjamin Baker, Messrs. John Aird and Co., and the great men associated with the work, the name of Sir Ernest Cassel deserves honourable mention. It is the habit of some people to sneer at financiers, and to regard them as parasites on the world's industry, but it was Sir Ernest Cassel who came to the rescue of the Egyptian Government when it was in financial difficulties, through the Soudan War, and advanced the money that made possible the undertaking of the project. The prosperity of Egypt has been the result.

The Assouan dam is a type of work that is new in history, and in his account of "The Nile Reservoir Dam at Assouan," Sir William Willcocks suggests that it may prove to be the pioneer work for other similar undertakings all over the world. The point to remember is that the lands of Egypt are fertilised by the Nile floods. The waters pour down laden with silt, and the dam has to allow this rich mud to pass through the sluices in the time of flood, and then, as the flood begins to slack, to hold up the water for use in the season of drought.

Building began in 1898, and an army of workmen, engineers, mechanics, labourers and beasts of burden and all kinds of machinery were drawn as by a magnet to the neighbourhood of Philæ. Before them stretched the Nile, and it was their work to build up on the bed of the waters a solid foundation. Divers are men of marvellous skill,

courage and resource, but with a steadily flowing current, the task would have been one far beyond their strength. When the line across which the dam was to run had been determined on, the first problem was to get the bed of the river dry, to narrow the passage of the river, in fact, and deal with the bed section by section. There was granite in plenty at hand, for was not Syene, the old name for Assouan, the granite quarry of the Egyptian kings? Great boulders were hewn out of the rock, brought to a part of one of the channels just below the line of the proposed dam, and dropped in. Though they weighed tons, they were swept away by the current. The engineers were undaunted. Large masses of granite were collected, tied together by iron cables, and lowered into the Nile. At times the engineers were in despair of success by other means, and whole railway trucks, securely tied and laden with granite, were dropped into the gulf, and, at last, an effective barrier was made. Similar work was then started in the still waters above the site of the dam, and with the flow of the water checked, it became an easy matter to build a sort of graving dock, to make it watertight, to set the big centrifugal pumps at work, and to lay bare the foundations dry.

This was the most anxious moment for the engineers. The fixing of the first dam, done, as you will remember, so as to get quiet water to sink the second dam above the proposed foundation, had caused the waters to rise 10 feet. The completion of the upper dam lifted it 20 feet. When the barrage was projected, it was thought that the floor of the stream as it passed between the granite hills on either side was solid rock, but the engineers found, to

their dismay, that large areas of the bed were rotten, and it was by no means certain that with the pressure of water above the dams, the stream would not pour up through the fissured rock in overwhelming quantities. Events happily proved these fears to be groundless, and the engineers soon found that it was an easy matter for them to keep the bed on which they wished to lay the foundations of the dam perfectly dry.

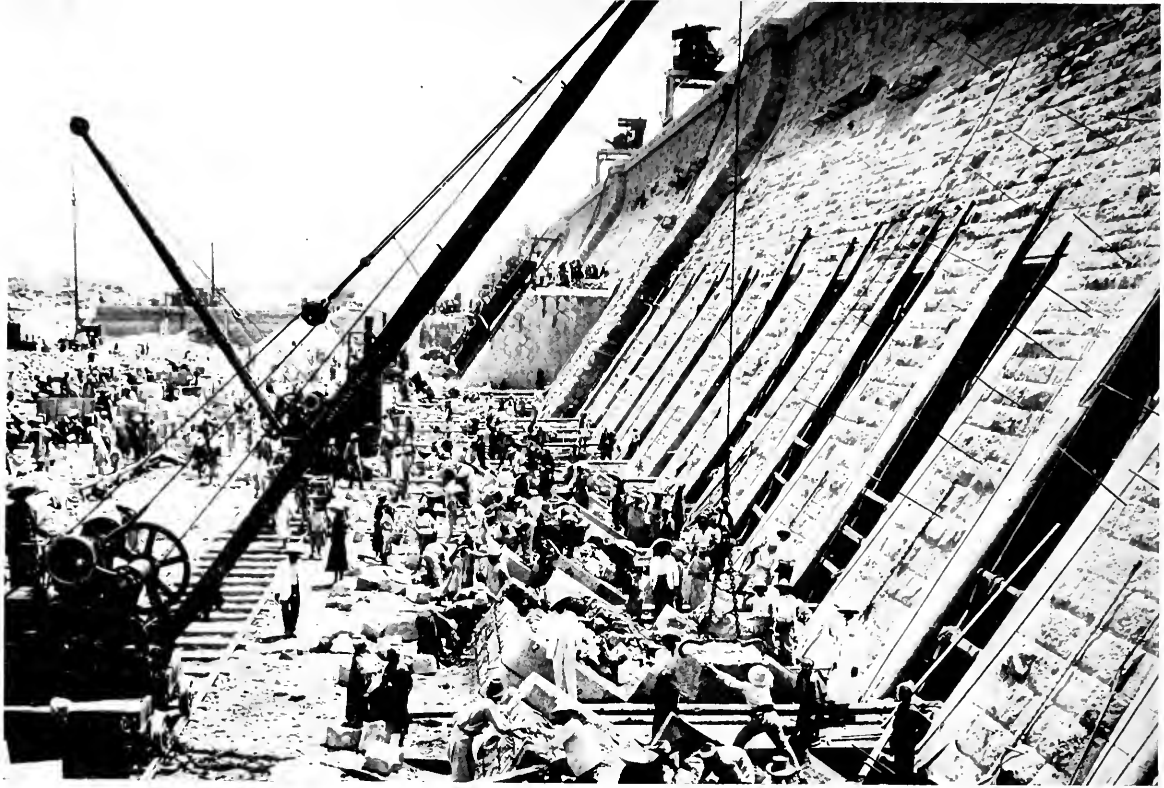
I have just mentioned the difficulty that the floor of the Nile at Assouan was not, as had been supposed, solid rock. This was the one really untoward circumstance in the whole building of the dam, and as the appearance of such unexpected troubles is one of the greatest trials that engineers have to face, I shall put down exactly what Sir Benjamin Baker said about it when he described the great works to the Royal Institution shortly after their completion. "When the rotten rock in the bed," he said, "was first discovered, I told Lord Cromer frankly that I could not say what the extra cost or time involved by this and other unforeseen conditions would be, and that all I could say was that, however bad the conditions, the job could be done. He replied that he must be satisfied with this assurance, and say that the dam had to be completed whatever the time and cost. With a strong man at the head of affairs, both engineers and contractors—who often are suffering more anxiety than they care to show—are encouraged, and works, however difficult, have a habit of getting completed, and sometimes, as in the present case, in less than the original contract time."

The French engineers at the Delta barrage, you will remember, had to construct their foundations by the un-

satisfactory method of dropping large quantities of stone into the river-bed. The foundations of the giant barrage at Assouan—and the Assouan dam, remember, is still the largest in the world—were built on the dry land with the great centrifugal pumps ready at hand to dry out any inrush of water. The dry land laid bare had to be prepared to receive the superstructure the engineers proposed to build upon it.

If you like to consider it so, their work was dentistry on a grandiose scale, and many a rotten tooth had to be excavated before the process of filling in could start. The base of the foundations was almost 100 feet across, and the crumbling rocks made it necessary at times to excavate 40 feet deeper down than was specified in the contract, and it caused the double difficulty of the rock taking longer to excavate, and of a correspondingly greater quantity of masonry having to be built in. That the 40 feet extra was a serious item with the Nile flood ever threatening to rush in and spoil the half-completed work, can be realised from two statements: (1) That the greatest height from the foundation of the dam was 130 feet; and (2) that five times the estimated amount of excavation work had to be undertaken. There is nothing very peculiar about the structure of the dam itself, for the main principles of dam construction have long been known. With the foundations firmly excavated huge shells of local granite were built, and these were set in that wonderful material British Portland cement, a substance that grows more and more solid the longer it is subjected to the action of water. The space in between the vast walls was filled with rubble and rough stone all carefully laid by hand, and the

whole was made solid by what is known as cement mortar, the substance consisting of four parts of sand to one of cement. The face work of the dam was of rough ashlar, except the sluice linings, which were finely dressed. As often in big engineering exploits, the difficulty of the work lay in the fact that the whole was a race against time. If the works did not reach a certain stage by the time that the Nile rose in flood they would have been overwhelmed and destroyed. The co-ordination of skilled and unskilled work necessary staggers the imagination. There were the native labourers working under their local foreman, the Italian quarrymen hewing and chipping granite, the crane men carrying hither and thither their burdens of stone, or pulling away the rotten rock, the blasters loading their charges of explosives, the railway workers laying light lines as they were needed, and organising their makeshift traffic, the smiths hard at it with their ironwork, the masons laying the granite blocks as they were brought to them by the giant cranes, the cement and mortar mixers with their special machinery, the pump men ready to deal at a moment's notice with an inrush of water, the doctors called on to maintain the health of the great settlement whose inhabitants were ignorant of the first principles of sanitation, the store-keepers and those responsible to see to it that the life in the settlement proceeded smoothly, and dozens of other classes of men, all co-operating for the single object. East and West jostled in amazing contrast—steam-navvies with donkeys and camels, workmen using the newest methods of the engineer, and workmen toiling as they did in the days of the Pharaohs; the whole supervised by a band of English engineers. We can be proud



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HEIGHTENING THE ASSOUAN DAM

of the achievement by which this city of Babel was organised to work together for their single aim, and to complete in four years a task that the contract laid down was to be done in five.

I have said nothing so far about Sir William Willcocks' design, but you will perhaps have heard of the opposition made to the project by certain archæologists on account of the submerging of Philæ. The dam was originally designed to be 100 feet high, but as a concession to popular clamour, the height was cut down by 26 feet, so as to prevent the complete immersion of Philæ. Fortunately, the International Committee that considered the plans made such stringent conditions as to the strength of the work, that the barrage, when completed in 1902, while nominally strong enough to hold back 35 milliards of cubic feet of water, was really strong enough to support the pressure from double the amount. Dramatic success followed the earlier undertaking, and it was in a very short time decided that Philæ must be sacrificed, and the height of the dam raised. The new scheme was completed and formally opened in December, 1912.

The raising of the barrage was a less difficult problem than the original construction. But a difficulty always present in the minds of the engineers, though seldom thought of by the man in the street, had to be surmounted. It is a general law of physics that substances expand when heated, and contract when cooled. For this reason, a gap is always left between the ends of railway lines, for otherwise, on a warm day, the rails would expand and buckle into curves. In large bridges, too, arrangements have to be made to allow the whole structure to move as a result of this

expansion. At Assouan, it was clear that trouble might arise if the new masonry was firmly bound to the old without sufficient time being allowed for the new and the old to harmonise in their movements, and so a peculiar method was adopted for the thickening of the dam. The face of the old wall had a number of steel rods built into it, and the new portion thickening it was built between 2 inches and 6 inches away from the old, deriving its support from these rods. Obviously, this space had eventually to be filled up, and cement was employed for the purpose. The cement was delivered into the space by flexible piping after two years had been allowed to ensure that the temperature had settled down. When the thickening had been satisfactorily completed, it was an easy matter to raise the height of the dam by building on the top of the structure.

So far I have said nothing about the locks that are required for these barrages. The Nile is a navigable river, and provision has to be made for passing boats between the upper and lower streams. At Assouan, the difference of level is 105 feet and the ships negotiate this by means of a flight of four locks. When you learn that the largest of the lock gates are as much as 78 feet 9 inches high, you will realise the magnitude of the task involved when the decision was made to increase the height of the barrage. An ingenious system was adopted to meet the difficulty. An entirely new pair of lock gates was fitted for the first of the locks and each of the old gates was lifted from its bed and taken to the recess below it. You have only to think a moment to realise that the shifting of the gates involved taking them over the lock sills. This was effected

by laying rails on the floor of the empty lock and continuing them from lock to lock, keeping the level constant by a mass of piled sleepers. When the gate had successfully reached the position required the sleepers were gradually removed, and the gates placed in position. If you just consider what an unwieldy shaped thing a lock-gate is, and then remember that the heaviest of the gates thus to be moved weighed 92 tons, you can imagine the difficulty of the work.

The Assouan dam is now complete, and when it was opened on December 23, 1912, the Khedive of Egypt paid graceful homage to the old religion of the country. The ancient Egyptians believed that the river was presided over by the Nile god Hāpi, whose praises are sung in the lengthy hymn found in the Egyptian collection of the British Museum; the handle that he used to manipulate the lever for opening the swing-bridge across the locks very appropriately took the form of a silver statuette of Hāpi.

What other works on the Nile will future generations, or, indeed, our own generation, see inaugurated? Sir William Willcocks is one of those who can dream visions, and, what is more, can see effect given to his visions. He has already given a forecast of the vast possibilities of irrigation that still lie before Egypt. It may be that the engineers will place shackles on the great lakes, that they will get rid of the swamps that squander the life-giving stream, and that the Assouan barrage is only an early stage in the progress of the history of the irrigation of Egypt. Work such as this must continually go forward. We may be proud of the prosperity that we have brought to a people overburdened with debt, but the source of our pride must spur

us on to further efforts until we have brought the greatest possible area of the desert into successful cultivation.

A final word as to cost and figures. The cost of the original Assouan dam was £2,450,000. The amount of material excavated for it was 824,000 cubic yards, and the masonry built 704,000 cubic yards. The dam contained 180 sluice gates, giving a total free area of 24,000 square feet. The volume of water held back was about 35,300,000,000 cubic feet (over 1,300,000,000 cubic yards). The heightening of the dam has cost about £1,500,000, but as a result of the work, the volume of the water held back has been more than doubled, amounting to 81,190,000,000 cubic feet.

To give some idea of the meaning of these figures, I will quote again from Sir Benjamin Baker, who explained the old capacity of the dam as being roughly equivalent to the annual rainfall on London and its suburbs within a radius of 13 miles; or twice the volume of the colossal scheme projected for utilising all the available Welsh valleys as a water supply for London; or more than enough water for a full domestic supply to every city, town and village in the United Kingdom. If you regard the question from the point of view of the flow obtained, you got, with the old reservoir, a volume of water steadily passing from the reservoir equivalent to twice that of the Thames in flood. And since the date of Sir Benjamin Baker's address, these amounts have to be more than doubled. There is reason, I think, you will agree, for Englishmen to be proud of the achievement of the engineers in Egypt.

CHAPTER IV

IRRIGATION IN MESOPOTAMIA—WATERING THE GOLDFIELDS AT KALGOORLIE—GREAT SCHEMES IN CANADA—HOW WATER IS BROUGHT TO THE WORLD'S CITIES

Some four years ago, as the *Geographical Journal* reminds us, Sir William Willcocks read a remarkable paper on a scheme for the irrigation of Mesopotamia, and when the lecture was over Sir Colin Scott Moncrieff, referring to Sir William Willcocks' life, described it as having been a very eventful one. "He was," Sir Colin Scott Moncrieff said, "a very little boy one day in the hot month of May, 1857, when a despatch came to his father from Delhi, only 20 miles off, to say India was ablaze, and the Mutiny upon us. It was only through extraordinary risks and great danger that he and his party—the father a very gallant soldier, the gentle wife and five little boys—managed to escape. It was too much for the mother, but the boys, I am glad to say, are all men now, and have all faithfully served their country. When I went to Egypt, in 1883, Sir William Willcocks was one of the first Indian engineers to join me. He had served under me in India for some years before. I think I may claim him as a pupil of my own, and, as very often happens, the pupil soon surpassed his master. His life in Egypt was full of event. For instance, walking after dark, about midnight, from the railway station to his boat on the Nile, he tumbled into an open

grave, and when he stumbled out the watchman went at him with a stick, mistaking him for a demon. A remarkable chapter of his life was on one occasion when the Nile flood did not rise quite to the proper height, and a large tract of country in Upper Egypt was left without water flowing over it. There was a canal about 200 feet wide and 20 feet deep, which, if the water could only be held up in it for a few feet and diverted over the land, would do all that was wanted. Willcocks stuck his bed on the bank of the canal, got together the peasants of the whole province, and for three days and nights worked at it till the water rose and flooded the plain. The people were so delighted with what he had done that they went to their mosque and insisted that this Christian should go with them and thank God. This is a very unique experience. You can understand from these little traits what Sir William has been doing. He is not the conventional type of man."

In the last chapter, we read of one of the great successes with which the name of Sir William Willcocks will always be associated, the harnessing of the river Nile. I want now to write shortly of the great project that he has designed in Mesopotamia, and that is awaiting the long-deferred co-operation of the Turkish Government to be carried into effect. Sir William Willcocks some years ago, at their request, studied the position of Mesopotamia, and suggested a scheme whereby the country could be efficiently irrigated. He started, plans and levels in hand, from the spot where Jewish tradition placed the Garden of Eden, to follow out the traces of the four rivers described in the early chapters of Genesis. As he proceeded on his journey, he was able

to read in the country he passed through the details of the Bible history. From the disposition of the country, he could see how, so long as the development of the country was confined to the low-lying lands blessed with water clear of silt, everything in the delta of the Tigris and Euphrates went on smoothly enough. But the pressure of population made the work of development advance into the parts where there was no clear water, and then the difficulties began. In the language of Genesis, the world became full of violence. And so the peoples began to spread up the rivers, and they found themselves forced to protect themselves from floods by the only means they knew of—the shutting off of the waters of certain of the branches by earthen dams. You have all read in your childhood of the Flood and of how Noah devised the Ark as a means of escape. This is what Sir William Willcocks writes of it: "The struggles between the different communities, and the terrible consequences which might result, intimidated the more thoughtful members of the community, of whom Noah was one, and he prepared for the worst. He built an Ark of the poplar wood so common in the Euphrates valley, and pitched it inside and out with bitumen from Hit, just as the boats and coracles on the Euphrates are pitched to-day. A settler, probably in the lower part of the delta, south of Kerbela, where the deserts, moreover, are strangely degraded and low, he felt the full force of the inundation. A massive earthern dyke was thrown across the head of the Sakhlawia, the flood discharge of the Euphrates was doubled, and instead of the waters rising 16 feet, as in an ordinary inundation, they rose 15 cubits, or 24 feet, and not only was the cultivated land

under water, but the deserts themselves were submerged." The story, with all its dramatic intensity, conveys the moral of the danger of interfering, without full knowledge, with the great natural forces of the world; and to the modern engineer the lesson to be learnt from the story of the Flood is that the floods of the Euphrates will have to be controlled when any serious development of the country is undertaken.

The history of Mesopotamia is the history of canals and waterways, of great floods rendering man's early efforts futile, of wars resulting in the neglect of the great waterways, and of great tracts of the country lapsing back into its primitive barren desert.

What are, in broad lines, the proposals that Sir William Willcocks has submitted to the Turkish Government? His first anxiety is to rid the Euphrates from the danger of floods. This he has proposed to do by cutting an escape for the flood waters of the Euphrates, and discharging them down the depression of the ancient Pison, the first of the four rivers of Genesis. The cost of this great cut, and of the works necessary to control it, would be £350,000, and he has estimated that on their completion the cultivated area will be doubled, and the yield of wheat trebled along the Euphrates.

It is proposed, again, to run a huge central canal through the delta between the Tigris and the Euphrates, to irrigate 3,000,000 acres of the best land of Mesopotamia. It will give you some idea of the great volumes of water to be dealt with when I tell you that to the north-west of Bagdad, between the Tigris and the Euphrates, is a great depression, known as the Akkar Kuf Lake. In periods of low water

this lake has an area of 40 square miles. In times of flood it extends over 300 square miles, an expanse about twice that of the Isle of Wight. The level of this lake is 35 feet below that of the Euphrates, and 10 feet below that of the Tigris. The lake is already fed from the Euphrates by the Sakhlawia, the ancient Hiddekel of Genesis, and it is proposed that it should be utilised to act as the source of the central canal. For this, both the Euphrates and the Tigris require to be controlled. The problem for the Euphrates is—on paper—the easiest thing in the world. Regulating works would be placed on the Sakhlawia to check the flow into the lake, and on the Euphrates itself down stream of the Sakhlawia would be placed a barrage with sluices to hold back the main river and ensure a constant supply.

The proposals as regards the Tigris are a little more complex. Far north of Bagdad at Beled, where the river is 60 feet higher than the lake, a weir would be constructed, and from upstream of this weir a canal would be drawn to irrigate the rich lands north of Bagdad, the water having an escape into the lake, and the plan at once providing an adequate supply to the lake, and securing the means of keeping the canal free from silt. From the lake would run the great canal close to the right bank of the Tigris.

The question of the Euphrates flooding, and of how that can be prevented, has already been considered, and the left bank of the canal would serve as a great dyke to check the Tigris from overflowing its banks into the central delta. On it, too, would run a railway that would provide the means of bringing the produce from the irrigated land to the markets where they are required.

A beautiful feature of the scheme is the way in which

the lake would act as a filter. For reasons that I need not go into, the silt that is so desirable in Egypt is a source of danger to the cultivator in Mesopotamia, and as the silt-laden waters of the Euphrates and Tigris discharge themselves into the lake the silt will sink and be trapped, and pure water will flow into the lands to the south of it.

The project, which is grand in its simplicity and its comprehensiveness, would eventually irrigate 6,000,000 acres, and if the Government would carry it through, would at once supply half of this area. In terms of its results, it would mean to the world 1,000,000 tons of wheat annually, 2,000,000 cwts. of cotton, millions of sheep and hundreds of thousands of cattle. To give this produce an outlet to the markets of the world, Sir William Willcocks has completed his scheme by formulating the plans for a network of railways to run through, eventually, from Bagdad into the coastline of Palestine.

Speaking with full confidence before the Royal Geographical Society, in November, 1909, he summarised his plans in the following striking words:

"I know that in these western countries of Europe, where rainfall is timely and abundant, and where rain and disaster cannot overtake a country in a day, we are apt to imagine that works of restoration must also take long years to bear any fruit. But in the arid regions of the earth it is not so. There the withdrawal of water turns a garden into a desert in a few weeks; its restoration touches the country as with a magician's wand. In her long history of many thousands of years, Babylonia has again and again been submerged, but she has always risen with an energy and thoroughness, rivalling the very completeness

and suddenness of her fall. She has never failed to respond to those who have striven to raise her. Again, it seems that the time has come for this land, long wasted with misery, to rise from the very dust and to take her place by the side of her ancient rival, the land of Egypt. The works we are proposing are drawn on sure and truthful lines, and the day they are carried out, the two great rivers will hasten to respond, and Babylonia will yet once again see her waste places becoming inhabited, and the desert blossoming like the rose."

Sir William Willcocks's dream has not come true as yet. The party of the Young Turks, who, we thought in Europe, were to regenerate Turkey, have failed to do the good work expected of them, and the irrigation of Mesopotamia remains a dream for the future to see realised. I have written at length about the triumphs of the engineer in Egypt, and have thought it only fair to give you the other side of the picture in Mesopotamia. The story is a striking object lesson of the need of a strong government. On this the work of the engineer, just as the whole progress of civilisation, depends—a thought that may help you to preserve a sane view of life when you come to see the reckless way in which sections of a people are from time to time attempting to scrap the great machine of government on which our whole prosperity depends.

From Mesopotamia and its troubles, let us pass to Australia. When Sir William Willcocks was writing about the Assouan dam and irrigation generally, he made the comment that Australia would have benefited vastly had the Government of that country paid to irrigation a portion of the attention they have given to improving means of

communication. Only a few years have elapsed since his statement, but already the idea of irrigation has taken a firm hold, and the Australian agriculturist is realising the value of the system. It was a terrible lesson, indeed, that brought home the importance of the work, and the years of the Great Australian drought, when men and horses, cattle and sheep died for lack of water over great tracts of country, will long be remembered as one of the great catastrophes written red in the history of the world. Instead of writing generally of the great irrigation schemes that have been promoted and carried through by the Commonwealth and the States Governments, which you can read of in any up-to-date book on Australia, I will describe one that was of such a daring character, so novel in conception, and so conspicuously successful in its execution that it can claim the right to a more than passing reference in these pages. What was the problem? Gold had been discovered at Coolgardie, 363 miles from the port of Fremantle, on the west coast of Australia. The first 100 miles from the coast run upwards over granite ranges, about 1,200 feet high, and then the country continues to rise through a series of broken rolling plains. The district is almost waterless, very hot in summer, with a paltry rainfall of about 7 inches. Before the discovery of gold, in 1892, the inhospitable character of the country was such that a man who had traversed it got the name of being an intrepid explorer. With the discovery of gold, men made a rush to the fields, braving hardships and risking death. The Government did what it could; it excavated tanks and built dams, but with all its resources utilised, it only succeeded in reducing the price of water from 2s. 6d.

a gallon to 70s. for 1,000 gallons. Meanwhile the railway crept up to the fields, but owing to the difficulty of getting water, its cost to the railway was the amazing sum of £1,000 a day during the summer months. An attempt was even made to secure water by boring, and the promoters of this scheme bored down 3,000 feet through the solid granite before abandoning their idea in despair.

In 1895 Sir John Forrest visited the goldfields, and to the astonishment of Australia, he announced on his return that he proposed to have water pumped up to the goldfields. In the Overseas Dominions, when once they have decided on doing a thing, they waste no time in setting to work, and in 1896 Sir John Forrest brought in a Bill for the construction of a reservoir to dam up the Helena River, near Fremantle, and to pump water out at the rate of 5,600,000 gallons a day up to the miners at Kalgoorlie and Coolgardie, at an estimated cost of £2,500,000. It is never necessary to do more than bring forward an original idea if you want opposition, and Sir John Forrest got it in plenty. He stuck to his guns, however, and by 1898 had got the Bill hustled through the Legislative Assembly.

The first thing to do was to secure the supply of water that had to be pumped. About 30 miles from Perth two great arms of granite jut out across the narrow valley at the bottom of which flows the Helena River. It was decided to dam back the stream with a great barrier of concrete. As the reservoir was to hold 4,600,000,000 gallons of water, there had to be no risk of weakness, and to ensure safety the engineers dug their foundations 100 feet in places below

the level of the river. They built them of a width varying from 85 to 120 feet, and then let the dam taper till it was 15 feet wide at the top.

The main interest of the work lay in the vast pipes that were to carry the water and in the pumping engines. Each pipe was 28 feet long, was made of steel plates $\frac{1}{4}$ inch thick, was 30 inches across, and weighed about $1\frac{1}{4}$ tons. Sixty thousand of them had to be used to take the water to where it was wanted. The pipes were of an entirely novel type, each pipe being made in two semi-circular sections, and an hydraulic machine ensured the joint being tight. The pipes had to bear an enormous strain, and so each pipe before it was put in position was tested to see that it would bear the strain of 400 lb. on each square inch of surface. Pipes of these dimensions and in these numbers are not to be got everywhere, and when you remember that the total contract price for their delivery in West Australia was £1,025,000, it will not come as so great a surprise that the two Australian firms who secured the contract should have erected special works for carrying it out.

Captain Amundsen, I remember, after returning from the South Pole, said in public that the chief factor on which success in Polar exploration depended was thorough and careful organisation. The same is true to an extraordinary extent in engineering, and of this the Coolgardie water scheme gives a striking example. Briefly, the problem was to pump 5,600,000 gallons per 24 hours against a total estimated head, including friction, of 2,700 feet through a pipe 30 inches in diameter, and, roughly, 330 miles, the speed of the water through the pipe being taken at about two feet a second. Eight pumping stations were installed.

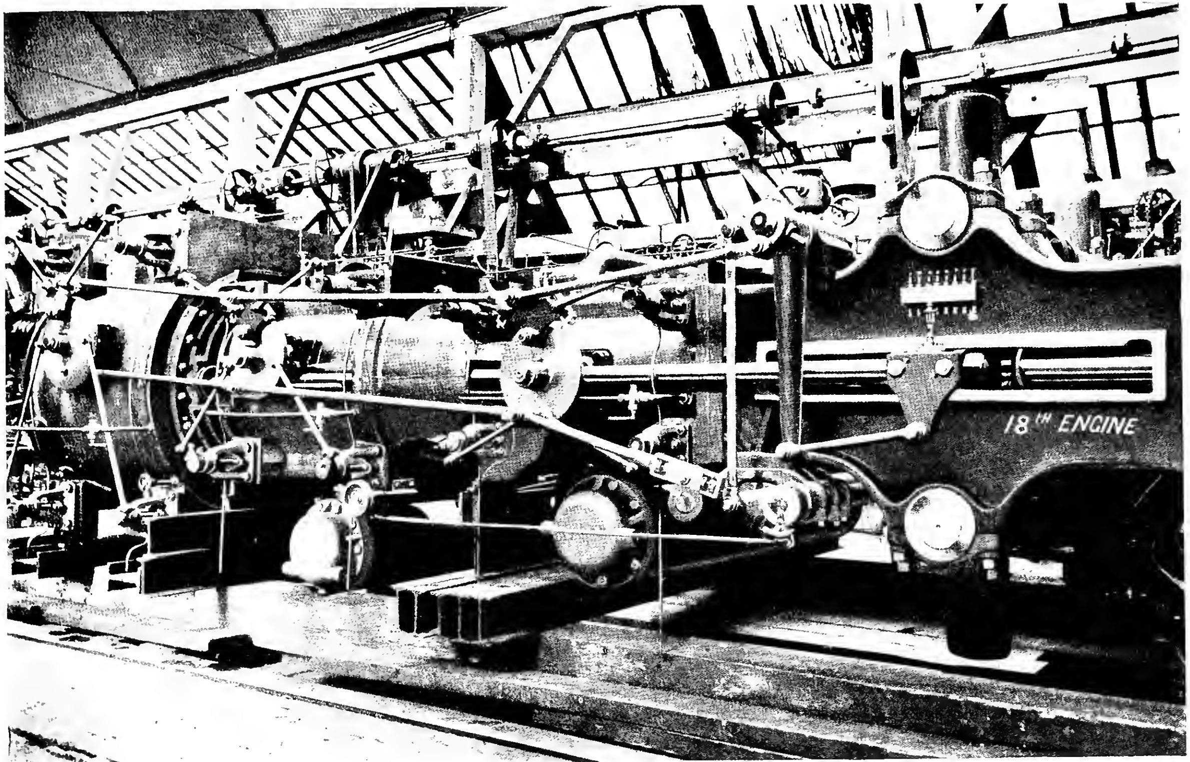
As the work is unique, we will trace the water from station to station.

From Stations 1 to 4, in each station there are three complete sets of pumping machinery and boilers, any one of which is capable of pumping 2,800,000 gallons per 24 hours against a head of 450 feet, so that to get the full quantity of water two sets of engines and pumps are always pumping together into the main, and one set is "spare." From Stations 5 to 8 inclusive, there are at each station two sets of machinery, each set being capable of pumping 5,600,000 gallons per 24 hours against a head of 225 feet, so that while one set is pumping, the other set is "spare." Station No. 1 is situated close to the foot of the great dam on the Helena River. The water is elevated 421 feet in daily work into an open concrete tank of a capacity of 468,000 gallons, situated at No. 2 Station, the total distance from No. 1 being about 1½ miles. From No. 2 Station the water is pumped up about 360 feet through 23 miles of main to the first regulating tank of Baker's Hill, about 1,080 feet above sea-level. This tank is of concrete, with a capacity of 500,000 gallons. The water runs from Baker's Hill by gravity to a second regulating 500,000-gallon concrete tank at Northam, 18 miles farther on, the Northam tank being 94 feet lower than Baker's Hill. Still falling, the water reaches the great tank at Cunderdin, which holds 10,000,000 gallons, and is 78 miles from the Helena reservoir. Stations 3 to 7 pump the water against a steady rise to the 8th station at Dedari, a distance of 217 miles from Cunderdin, and situated at an elevation of 1,457 feet. Each station is provided with concrete tanks of 1,000,000 gallons capacity, which act as combined receiving and suction tanks. From

Dedari, the water is pumped a distance of 12 miles to the main service reservoir at Bulla Bulling. This reservoir is of concrete, reinforced with barbed-wire strands, and holds 12,000,000 gallons. Bulla Bulling supplies a small service reservoir of 1,000,000 gallons on Toorak Hill, overlooking the town of Coolgardie, the mean elevation being 1,525 feet. From Toorak tank the water runs by gravity to a reservoir on Mount Charlotte, which supplies the town of Kalgoorlie.

Several firms tendered to supply the machinery to carry out the work, but the contract went to Messrs. James Simpson and Co., of London. There is much of interest that could be written about the machinery employed to effect the pumping. I must content myself, however, with drawing attention to an ingenious arrangement whereby the water in the mains is made to pass through the condensers of the engines, and the two sets of double-acting plungers ensure that one of them shall always be sending water to the mains, so that the delivery is uniform and shocks are entirely avoided. Perhaps, however, the most important part of the machinery to the high-working economy is what is known as the Worthington high-duty attachment, by means of which the excess of power exerted by the steam in the cylinders at the beginning of the stroke is stored up and transmitted to the end of the stroke when the steam pressure, owing to expansion, is smallest.

As I have said before, it is only necessary to bring out a new idea for the pessimists to start prophesying disaster. Some of the local experts, for instance, went about saying that at each revolution of the pumps the pipes would receive a blow of 60 tons to the square inch; but, needless to say, the accomplishment of the scheme proved



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ONE OF THE PUMPING ENGINES OF THE COOLGARDIE WATER SUPPLY SCHEME

that nothing of the sort occurs. Personally, I have been led rather to distrust these rash prophecies that one hears from time to time, and on such occasions I call to mind the story—probably apocryphal—that is told of the late accomplished golfer, Freddie Tait, and his father, the famous philosopher. According to report, Professor Tait investigated the mathematical principles governing the flight of a golf-ball, and concluded that it was mathematically impossible for a ball to be driven for more than a certain distance. The same afternoon he was on the links with his son, who, making a splendid drive, sent the ball several yards beyond the extreme limit his father had worked out as possible. As I said, there may be no truth in the story, but it is a good working rule to exercise the same distrust when you hear that a thing is theoretically impossible as when you hear a politician backing his views by saying "as history teaches." Theory is of paramount importance, the most valuable lessons can be learnt from a study of history, but the validity of the conclusion in either case depends on the capacity of the man who attempts to draw it.

One of the greatest problems in connection with the plant for the Kalgoorlie scheme was to get it, with its weight of 3,500 tons, out to the colony, and to have it sorted out and sent to the proper places up country. There were twenty groups of machinery, each consisting of an engine and boiler, and these had to be distributed over 330 miles of country. Obviously, if mistakes were made in consigning it would be a very expensive job to rectify them. An ingenious system of shipping was adopted which worked perfectly. Each group was given a distinctive colour and

letter, and every part of the group was painted with the distinctive group colour to which it belonged. When the parts were cased, one end of the packing case was also painted with the correct group colour. In addition, each case or package was numbered consecutively, and marked with the different group letter. All marks were in duplicate, one set being painted on the case or package, and the other stamped on sheet-tin tabs, which were fastened on to the cases or packages. No parts of different groups were allowed to be packed in the same case, and by this means all trouble was avoided. The railway, shipping and wharf men were each supplied with coloured group key plans, and so were able to pick out at once the various cases and packages belonging to each group, and to send them on to their correct destination. The whole was a triumph of perfect organisation, for though there were some 5,000 packages to be distributed, the only complaint received from the erection staff as to missing material referred to one ½-inch hydraulic valve.

The great work was successfully completed in 1903, five years after it was begun, and as it is usually described as being a unique piece of hydraulic engineering, it may be of interest to have a few of the figures relating to the scheme in tabular form:

Total cost	£3,252,700
Capacity of reservoir	4,600,000,000 gallons
Cubic yards of concrete in reservoir wall	82,000
Area covered by operations	16,000 square miles
Total length of 30-inch main	351½ miles
Number of towns served	26
The time taken by the water in going from the reservoir to Kalgoorlie	4 weeks

Year's total of water supplied ..	1,058,931,000 gallons
Year's working expenses	£70,972
Year's net revenue from scheme (1910)	£166,696
Interest on capital available for Sinking Fund and interest	About 5 per cent.

We are apt to associate irrigation with the warmer countries alone. Most of us have heard of Aden and its huge water tanks, and we have already seen that it was because of the experience the British engineers had got of irrigation works in India that they were able to carry through the gigantic scheme that was necessary to save Egypt from bankruptcy. From Egypt, Mesopotamia and Australia we will pass to Canada, and we shall see that there, too, the engineers have found that they can increase the productivity of the land by providing an artificial supply of water. Nature in the New World acts on a more grandiose scale than in the Old, and we can only admire the energy of that great undertaking, the Canadian Pacific Railway, which has quietly put in hand in Alberta a scheme for irrigating a block of land that is an eighth the size of England and Wales. It is a work on a large scale, as you can gather from the fact that when completed it will provide an irrigated area equal to more than a fifth of the total amount of irrigated land in the United States. As we have seen the general principles on which work of this kind is carried out, I will say no more of the project than that elaborate precautions are being taken to ensure that the waterways shall be free from all risk of leakage and breaks, and that the amount of material moved in the different sections will amount to 24,750,000 yards. The Company has decided to do the work thoroughly, and is

making itself responsible not only for the main and the secondary canals, but also for the distributing ditches that carry the water to the individual farms.

Great engineering works are closely interdependent, and if evidence were wanted to prove the economic value of such achievements in increasing the wealth of a community it would be amply shown in the fact, I think, that this great project, which provides for 2,900 miles of waterways, has, according to the Company's own claim, been put in hand for the definite purpose of transforming a large area at present unsettled and non-traffic producing into a closely settled and prosperous farming community, with the attendant traffic receipts that always result from such districts. For this reason, the scheme has not been undertaken to make money from the irrigation project itself, but as a colonisation and future traffic-producing investment.

A final word, before I close this chapter, on the methods employed to furnish large cities with an adequate water supply. As you will realise from the special chapter that I have devoted to London, the metropolis alone requires for its people a volume of water about 20 feet square moving steadily towards it at the rate of two miles an hour; and if one looks at the civilisation of the Old World, one can realise at once that the problem of the water supplies to the big centres was one that closely occupied attention. If Rome were represented to-day only by her aqueducts, we could deduce from the ruins an estimate of her real greatness, and form an idea of the vast influence she wielded by the water channels that she laid down in various parts of her Empire.

The sources of supply to a city are vastly different from those prevailing in the country. In many cases, the country house relies on a large cistern that catches the water that falls on the roofs in rain, but the town relies either on wells, or on great rivers, or else on vast lakes in which the water is banked back, and flows to its destination through the force of gravity. All these sources of supply are often employed. We are so apt to think that we know all about an object with which we are familiar without really understanding the principles on which its working depends, that I am giving a brief account of the fundamental cause of springs. The earth's crust in any part of the world contains at a higher or a lower level strata that are impervious to water. The water above these strata runs along them, and accumulates in fissures and pockets, and to get a supply it is only necessary to bore down into one of these pockets. It may be that the water will issue of its own accord when such a pocket is cut into, for if the impervious stratum has been bent or is inclined, the pressure of the water on the higher levels will drive it out. In some cases it is necessary to use pumping apparatus. Where artificial boring has taken place, the well is known as an artesian well (from Artois, the town in France where they have long been in use), and you will probably be surprised to hear that London derives one-fifth of its water from this source alone, the Bank of England itself being thus supplied. It is a matter of importance in cities to go deep enough below the surface to ensure that the supply is not tainted by surface conditions.

The authorities that have to keep a great city supplied with water have to take a broad outlook on their problem.

Few sights are more pitiful than those which can be seen when a water famine threatens a town, and the poorer classes flock into those parts where a supply can still be obtained. A heavy penalty indeed threatens a modern community if the water supply fails. Disease follows hard upon the track of discomfort, and little that can be done is of any avail.

Whereas in the Kalgoorlie water scheme we saw that the engineers had to pump their water against gravity, the usual method is for advantage to be taken of gravity to bring the water to a town. Far away in the country great reservoirs are built, and big dams constructed to resist the force of the pent-up waters, for if these escape, they threaten the countryside with devastation. The sad story of one such catastrophe is still remembered in Sheffield. In March, 1864, a landslip occurred near to the Dale Dyke reservoir, some six miles from Sheffield. The reservoir was full of water, and while the town was peacefully sleeping the embankment gave way, and hundreds of millions of gallons poured like an avalanche on to the town. Nothing could stand in the way, and when the flood had spent its force it left a wrecked town in its wake, with a tale of 268 dead. The water engineers learnt their lesson that night, and the reservoirs have now been so built as to avoid all chance of such a catastrophe.

Gradually the big cities are seizing on the great catchment areas of the country to supply their needs. A scheme has even been put forward to impound the water in some of the Welsh valleys, and to bring it across England to London, a proposal that sounds almost grotesque, but is less so when you remember that the authorities have to

keep available day by day a supply for 7,000,000 of people.

The work of the water engineer is no sinecure, and he has to think in vast quantities. The iron pipes of his mains will be as much as $1\frac{3}{4}$ inches thick. He has to consider and provide against the dangers of frost. He must equip his works with a constant succession of valves to cut off the supply at a moment's notice should a burst occur. There must be reservoirs for filtering and purifying the water, great pumps for manipulating it, and anchors to keep the heavy pipes in place when they curve as they sweep on to their destination. Levels and gradients must all be taken into account to ensure that an undue strain is not imposed. A close watch must be kept to see that there is no unnecessary waste and great discretion exercised in controlling the sources, to avoid on the one hand the danger of floods, and on the other the risk of famine. The waterworks of a city look unromantic enough, and scarcely suggest the skilled work that must be spent upon them. They are, however, a vital factor in the well-being of every civilised city.

CHAPTER V

POWER AND ITS SOURCES—WIND, COAL, STEAM, ELECTRICITY, OIL, GAS, THE SUN AND THE ATOM

One of the prime duties of the engineer is to manipulate and modify the forces that play upon the world. Powerless in his own strength to battle against a raging torrent, he is called upon to devise means to restrain it and to turn its destructive force into the service of mankind; helpless before the shocks of earthquake, he is bidden to advise a type of building strong enough and pliant enough to withstand its attacks; utterly insignificant before the sea when driven by the tempest, he has cast upon him the obligation to prevent the shingle being driven to silt up our harbours, and to hold back the sea itself as it threatens to prey upon our coasts; he must provide warmth against the inclemency of the elements, and must devise shelter against the sweltering heat of the sun, and over and above all he must keep his fellow-men continually in possession of the energy that enables them to do the work of the world without immediately using the strength of their own muscles.

Let us glance for a moment at a few of the innumerable forces that are continually harnessed to the bidding of man. There is the wind driving the windmills, pumping water off the low-lying lands, bringing it up from below the ground, and speeding the ships across the trackless seas. There is steam giving the power to factories that are so

many as to defy even the statistician's imagination, making battleship, liner and tramp independent of the wind, hauling our trains, propelling motor cars, and, above all, generating the handiest of man's servants—electricity; there is electricity itself superseding its own parent steam, lighting our houses, giving cheap power to our factories, performing services of nearly every conceivable kind; there is water that before the age of steam was one of man's kindliest servants, turning the wheels of his mills and relieving him of much of the tedious monotony of his work, and that now, after steam has had its great age of supremacy, is again coming into its own, by driving mighty turbines, as at Niagara, and generating electricity that is carried to far-distant cities, or that is used directly to form great arcs of flame which force the oxygen of the air into combination with the nitrogen to provide for agriculture the most valuable of all the manures; there are gas and many forms of liquid fuel that actuate the engine by utilising the force of the explosion when they suddenly combine with the oxygen in the air; there are the powerful explosives that rend the bowels of the earth, enabling men to remove hills, to drive tunnels, and to forge the deadliest weapons of destruction; the force of gravity, and even the sun itself and the waves of the ever-restless sea, have been harnessed and pressed into man's employment, so that his resources may be still further multiplied. All these forces and many others, terrible as they are in their stupendous magnitude, the engineer must control and dominate. And one and all, as I shall try to show in the course of this chapter, are derived from the great parent of all, the sun.

There was stern wisdom behind the men of old, and the men of to-day who pay their worship to the sun, for it is the sun and the sun alone that makes life possible upon the earth, and it is the sun that aids man in all his activities.

The wind was probably the first of the natural forces ever used to carry out the heavier work of man. For my own part, I am content to trace it back as far as the times of the old blind singer of Greece, Homer, and to recall to you that Homer gives us a full description of how the greatest of all heroes of romance, Odysseus, built a boat to escape from the enchanted isle where Calypso kept him a not unwilling captive, and elaborates in detail the way in which he fitted a sail, and, with the winds favouring him, sailed back towards his home in Ithaca. For long the power of wind held sway, and to-day, to see it toiling in its harness, you have only to go over to Holland or to the Broads of Norfolk to watch the windmills steadily at work, pumping the water off the land to prevent it lying stagnant and turning the meadowland into a marsh. Windmills are to be seen scattered all over the country, and in recent years they appear again to be coming into favour, and are being fitted especially to raise water from the wells in country districts and to store it for use as it may be required. The world is now threatened with the ending of its coal supply, and it is the dream of the engineers so to harness the winds that they will give a constant source of power. The objection to the scheme is at present that coal is the more economical force, as is shown by the way in which steam-pumping engines have superseded many of the old windmills that were formerly in use upon the Broads, because the use of coal, in properly constructed

engines, proves more economical in running than the windmill. Wind, however, has not yet been abandoned as a force. It still pays to construct huge sailing vessels, five-masters that can make quick passages across the Atlantic, and, indeed, to all parts of the world. It is not long since the amazing suggestion was made that our coasts should be equipped with windmills, that these should pump sea-water up into great reservoirs, and that a steady source of power should be got from the water as it ran back into the sea. I am afraid that the trouble about this, as about other schemes, would be that the cost of installing the apparatus would be so great that it would never pay to run.

But what, you will ask, has the wind to do with the sun? There are two chief sources of the wind. First, the earth, as it spins in space under the sun's influence, tends to spin through its own atmosphere, and we on the earth feel the air as it is left behind as a wind. Secondly, the air in the tropical regions is warmed by the heat of the sun. Warm air is lighter than cold, and therefore rises, its place being taken by the air from the temperate regions, while the tropical air having cooled, falls again towards the earth in the parts that are nearer to the poles.

Man cannot long have become familiarised with the use of the wheel before he set himself to wonder if it would not be possible for him to utilise the force of running water to turn a wheel for him, and so to get command of a force that would serve to grind his corn. The labour of grinding corn for bread had been traditionally severe, and large profits were obviously to be earned as soon as a means was devised for getting the rivers to do the work that

hitherto had always been done by hand. The primitive method is simple. There is a large wheel fastened to a long axle. The rim of the wheel is covered with open boxes, so arranged that water from above pours into them to fill the boxes on the one-half of the wheel, which empty as they reach the bottom, and come up empty on the other side. By the difference in the weight on the two sides of the wheel, it is kept constantly in motion. As it turns, the long axle turns with it, and by means of an arrangement of cog-wheels at the other end of the axle, machinery is driven. With the conquest of steam, white coal, as water power has been picturesquely called, fell into disrepute. Mills all over the country have been closed down, and it is only recently, as men have begun to realise that they are faced with the fear of a shortage of coal, that attention has again been called to the water of the world. The result is that a great section of men now look to it as one of the great sources of power to be tapped in the near future. Already, as I have mentioned, the great source of Niagara has been pressed into service. The water which before launched itself uselessly down the vast cataract is now led through mighty turbines, and the electricity generated from these is distributed to far-distant cities to carry on the toil that is the necessity of civilised existence. In Norway, too, in Switzerland, in Germany, and even in the Highlands of Scotland, the waterfalls have been harnessed and turned to the making of nitrates, and by this means the wheat famine that threatened the world has for the time being, at any rate, been avoided. In the "white coal," the world has a great store of energy of which it as yet hardly recognises the existence. At the British Association meeting in 1912 an

engineer read a paper urging on the members the desirability of taking full advantage of the many falls that exist in the Highlands, and of using their power to get energy independent of coal by turning the force of the falling water into electricity. But how, you will ask, is this energy derived from the sun? The water supply of the world is one of the most grandiose cycles in Nature, dependent, like all the cycles of Nature, on the force of the sun. The sun's rays falling on the earth turn the earth's moisture into vapour that is drawn up into the clouds. As the air that becomes saturated with water vapour in its passage across the great oceans cools, it is no longer able to hold the same quantity of moisture, which condenses and falls to the earth as rain. The rain swelling the rivers, makes its way to the sea, and the engineer, taking advantage of the law of gravity, by which the water tries to reach the sea, the lowest level possible, is able to trap and use some of that portion of the sun's energy which was taken to vaporise the water on the earth, and thereby raise it into the sky.

And now we come to steam that has revolutionised the face of the world, and probably done more than any other factor to increase the comfort of our life. The discovery that steam could be used as a motive power dates back to the Greeks and Romans. One of them discovered that it was only necessary to allow steam to escape through a series of nozzles supported by a carefully pivoted stem for the whole system to revolve, but it was not till modern times that the value of steam as a motive power was really determined. This is not the place for us to consider the steam-engine in detail, but the fundamentals of the engine may be described. Its essential parts are the furnace,

cylinder, valves, piston, connecting rod and crank-shaft. The admission of steam into the cylinder by means of the valve forces forward the piston, and when it has completed a certain portion of its forward travel the steam supply is automatically cut off by the valve and steam admitted in front of the piston, thus driving it back again. The valve allows the spent steam to escape or "exhaust" after it has done its work. The cycle of operation continues, the reciprocating or to-and-fro motion of the piston being converted into a rotary motion through a crank-shaft which also operates the valves by means of eccentrics keyed on to it. Such an engine is a simple double-acting engine, but there are many other forms known as "compound" in which the steam is further made to do useful work in other cylinders, of which there may be one, two, or three. Such engines are called double, triple, or quadruple expansion engines, according to the number of cylinders.

The uses of steam are too numerous to mention, and what boy is there who has not stood in wonder watching the railway engine hauling its heavy load of passenger wagons, or gazed at the great reciprocating engines in a ship's hold? To all of us the threshing machine has been one of our earliest delights. We have noticed the development of the turbine that enables steam to work continuously by quite a different principle, and that gives to the engine a circular motion direct without any of the movements to and fro that tend to tear a rapidly moving machine to pieces. We have seen steam pressed in to all sorts of strange uses—to hammer metals, to drive motor-cars, to work cranes, to destroy the germs of disease, and to operate nearly every conceivable machine

that man has invented. And steam, too, we derive direct from the sun. Steam, as you know, is got by heating water, and you can do this in various ways, by coal or oil, or by the direct heat of the sun itself. Both coal and oil are derived from the products of the great forests that flourished at a time when the earth was a vastly different place from what it is to-day, and now in the twentieth century we are setting free in the boilers of our engines and in the fires upon our hearths the rays of the sun that fell on this earth at a time æons before history had begun to be written. I should like to make this a little plainer, for there is nothing I know much more beautiful than the mechanism by which Nature keeps the balance between animals and plants. The animal, as you know, breathes in the oxygen of the air, and he derives his energy by breaking down parts of himself, or his food, into carbon dioxide, which then he breathes out. Naturally, if he has got a lot of energy from doing this, it would require a great deal of energy to recover the oxygen from this carbon dioxide. And this is the case. But the green leaf of the tree or plant contains a substance called chlorophyll, that is able by some marvellous mechanism to take hold of the energy of the sun's rays, and to use them to break down this carbon dioxide, to give back a portion of the oxygen to the air to be used up again by the animals, and to build up the carbon into its own tissues. The forest trees flourished and died while others grew in their stead, and in the process of time the country on which they stood has sunk below the level of the sea and the deposits of the waters have buried the coal measures beneath their silt. Then the land has risen again, and so it is that in working our steam engines to-day we are

unlocking the stores of energy that the trees of long ago stored up from the sunbeams that fell upon the earth.

If you were asked what was the most striking development of modern times, you would have some difficulty in answering, but you could make a good case for the view that it was the internal combustion engine. It has, at any rate, done more than any other force to drive the horses from our streets, and to make possible pleasant and rapid communication along the roads. The beauty of the internal combustion engine lies in this, that the energy of the fuel is used directly instead of it being necessary to get at it by the wasteful method of turning it into heat, and then passing it through steam. A mixture of the air and the oil to be exploded with it is brought directly into the cylinder of the engine. When the piston has reached the top of its stroke and the mixture of gas or vaporised oil is at its maximum compression, a spark in the cylinder explodes the mixture, which drives the piston down the cylinder, and so the process continues afresh. It may be of interest to note that so early as 1678 a patent was taken out for an internal combustion engine that was to be worked by gunpowder. The possibilities before the internal combustion engine are immeasurably great. The time will come when the world's store of petrol and of coal is exhausted, and then, instead of spending day by day the capital that was stored up for us in the way of coal, we shall have to trap the sun's rays on a gigantic scale. There can, I think, be no doubt, but that one, at any rate, of the most efficient ways of doing this will be to sow great tracts of country with quick-growing plants, to use these plants to absorb the sun's energy with their chlorophyll, to distil them in such a way

as to produce alcohol, and to use this alcohol as the motive power in internal combustion engines. The internal combustion engine is extending the sphere of its activities day by day. Railway locomotives have been constructed to use it, ships—it is hard not to write steam-ships—are being driven by it, small pumping and country house lighting plants are being installed all over the world on this system, and there can be no doubt that this type of engine is destined to still further development. And the oil and the gas again are products of the sun's activities, for both are derived from the forests that flourished in prehistoric times.

It is in electricity, however, that the engineer has his most conspicuous success, for there is no neater form in which power can be handled. It is, of course, a secondary source of power, in that respect like steam, for no man yet has devised a means for harnessing the lightning flash. Coal must be burnt, water must be allowed to fall from a height, chemical energy must be degraded, or work done in order that electricity may be produced. From the fundamental experiment that a piece of amber when rubbed will attract small pieces of paper, or dust, or fluff, man has passed to building vast machines that generate a stupendous amount of power, and distribute it to drive trains, to light lamps, to move the machinery in factories, to produce the fiercest intensities of heat, and to perform even such trivial services as the brushing of your hair at the hairdresser's. And electricity, whenever it is spontaneously produced in Nature, is the result of the energy that the sun sends down to us in its unfailing supply.

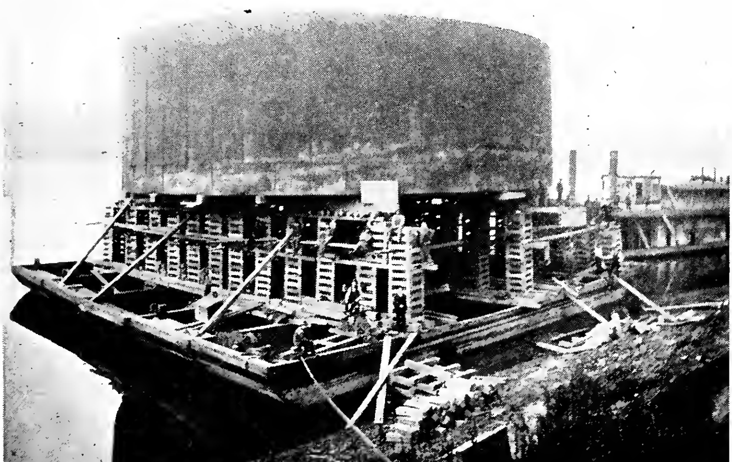
The force of gravity is still a mystery to us, and in it we have in a sense a source of power that is not derived

from the sun. When we take advantage of the water that hurries downwards to the sea, we rely on the principle that everything on the earth is struggling to get as near as possible to the earth's centre, and we can make it pay us its toll as it passes on its way. The force of gravity direct is at the basis of water power. It is used in the treadmill, the weight of the prisoner's body turning a wheel much as the weight of water turns a water-wheel, but the muscular activity of the man raising him constantly as he tends to fall. Advantage has been taken of it in irrigation works, which are arranged so that the bullocks that draw the water from the well walk down hill as they do the work; and countless other instances might be given.

The idea of pressing the sea into service has long been one of men's dreams. They have thought of using the tides by entrapping the water as the tide flowed, and making it turn their wheels as it ebbed. They have thought, too, of taking advantage of the vast energy that is running to waste in the waves, and from time to time one reads of cases where this has been achieved. The time, no doubt, may come when it will be found possible to do this on a large scale, but at present no work of any considerable importance has been done along these lines. Only a few days ago I heard of an ingenious system which was said to be working, whereby the energy of the waves was used. On a sloping beach sets of rails have been laid down, and a machine is let down along these below the surface. As the waves reach the shore, they move the hinged shutters of this machine, and as these are harnessed, useful work is done. But whenever the sea is dangerously rough, the machines have to be drawn up the rails, out of harm's

Photo: Messrs. C. J. Crandall & Co., Pasadena

A MOTOR WORKED BY THE SUN'S RAYS



A WONDERFUL ENGINEERING FEAT

This oil tank weighing 150 tons was raised out of the ground, taken down a hill, conveyed a mile by river, and then carried 200 feet up a steep bank to its new site

way. The waves, through the medium of the winds, are the result of the influence of the sun, but if ever general advantage were taken of the tides we should have an instance of man having drawn upon the moon as a source of the energy he constantly needs.

What of the sun itself? The idea of using it directly is another engineering ideal. You have heard of Archimedes of Syracuse, and how he focused the rays of the sun on to the mooring ropes of a hostile fleet and burnt them through. The story may or may not be true, but there is nothing impossible about it. Indeed, there was a case years ago in which the covering of a bed in the berth of a steam tug in Plymouth Sound was burnt by the concentration of the sun's rays through the glass deadlights in the side of the vessel. About the same time a fire was caused at Paignton by the ignition of some canvas on to which the globular lamp over an ornamental gate had concentrated solar rays. There are to-day practical engines at work that make use of the rays of the sun as the fuel for their boilers. Further, it has been suggested that the vast waste torrid spaces of the Sahara Desert will, in time to come, be the site of the world's great power factory. So far, the sun-engine is a great steam-engine, the credit for the successful invention belonging to Mr. Frank Shuman, of Philadelphia, and the sun's rays taking the place of the fuel. His method is to have a great series of iron boxes painted dark so as to absorb the heat. These are filled with water and covered with panes of window glass. On each side of the window glass are mirrors that reflect the sun's rays on to the glass above the iron water-containing boxes. The extreme heat of the tropical sun

turns the water in the boxes into steam, the steam is led by a large pipe to a specially constructed engine, is then condensed back to water and returned to the boxes to be used over and over again. The efficiency of the machine is such that in Philadelphia, which is far from being the most favourable of all possible sites, it is able to raise 3,000 gallons of water every minute to a height of 33 feet. The invention has aroused the interest of engineers; a specimen machine has been ordered for Egypt, and it may well be that a great future lies before it.

The use of compressed air is a factor in the manipulation of power, to which I must make reference here. Logically, it belongs rather to the class of instruments such as levers and blocks and screws and wedges, as a means of manipulating and applying power, and these, for want of space, I am compelled to pass over in silence. But compressed air is used for such a variety of purposes that a few may be referred to. In salvage work, we shall hear a good deal about it, for it is one of the chief weapons that the salvage man uses, making his sunken vessel air-tight, and then pumping air into it to displace the water. It is used in place of steam to fasten rivets, drive drills, and even to punch holes in metals. It can operate railway signals and drive trams along the streets, it can enable divers to work in diving-bells beneath the water, and is pressed into the service of municipalities for the sand-blasts with which many public buildings are cleansed.

The layman is so little apt to look on explosives as sources of power from the engineer's point of view, that I propose to give here a few instances of the great engineering feats that have been carried out by these means. But

before doing so I should like to point out that in this case, too, if we go far enough back, we can look on the sun as the source of the energy. The principle of the explosive is that it is a body with a vast amount of potential chemical energy, so stored that it can suddenly be degraded. Thus, in gunpowder, there is the carbon. We know what a powerful source of heat energy carbon can be, as, for instance, when it is burnt in the ordinary fire. The nitrate in the powder supplies the oxygen necessary for the process to take place, and the sulphur is another body that can give out great energy, as it is degraded to sulphur dioxide. The other types of explosive act similarly. They are bodies that are very unstable, and that, with the necessary stimulus, give up their store of energy, their solids suddenly turning with great violence into gases. I have been reminded of some of the uses to which the engineer puts explosives by reading in the newspapers of the dislodging of 30,000 tons of rock on Mr. A. J. Balfour's estate in East Lothian. Blasting on that scale is not done every day, and several of the newspapers recalled some of the other great feats that have been done in this connection. Among the more notable instances are the following: In the great slate quarries in Carnarvonshire a mass of granite had been left while the softer slate was being excavated. The rock, 214,000 tons of it, overhung the workings, menacing the quarrymen, and it was decided to blast it out. Galleries were cut, 5,000 lb. of blasting gelatine was put in place, and the whole of this vast quantity of material was blown bodily into the valley beneath. The blasting up of Hell Gate was another great achievement. Hell Gate was a group of dangerous rocks, close to New York, and that

it fully deserved its gruesome title may be gathered from the statement that it was estimated that one in fifty of all the craft navigating those waters was wrecked upon it. For over a year men were engaged in boring galleries. Four miles of tunnel were eventually made, and these were filled with dynamite. Electricity exploded the mass, and with this one gigantic explosion, 6 acres of solid rock were removed, and the passage cleared for navigation. I will give one further instance, of many, of the ways in which the engineer makes use of explosives to help him in his work. As you will read in the chapter on marine salvage, blasting is frequently used below the water, in order to salve a vessel, but the case of the *Chatham* was one of those where the blasting was undertaken to destroy. The *Chatham,* a steamer of 3,200 tons, had as her cargo, in 1905, 1,500 tons of super-phosphates, 500 tons of pig-iron, 800 tons of coke, 19 tons of explosives and 16 cases of detonators. In passing through the Suez Canal she came into collision and caught fire. As there was a danger of the fire reaching her explosives, she was sunk and submerged to a depth of between 25 and 30 feet. Two cases of dynamite floated out of the hold, and to their horror, the authorities found that from these nitro-glycerine was exuding. If this happened to come into contact with the pig-iron, there was a danger that chemical action might set off the whole mass of the explosives. The sunken *Chatham* was, in fact, a gigantic mine, lying right in the track of the steamers. The canal authorities having decided to blow the vessel up, took elaborate precautions. A force of soldiery was despatched to prevent any one approaching within six miles. Special charges were lowered down

into the ship, and from $3\frac{1}{4}$ miles away the fuses were fired. The column of mud, water, sand, and debris rose into the air to a height of nearly 1,000 yards, and it was 35 seconds from the time of the explosion before the mass shot up fell back to earth. The explosion damaged the bank of the canal, taking away a breadth of 35 yards for a distance of 120 yards in the neighbourhood of the explosion. But the steamers were then able to pass through the canal in safety.

In writing this chapter I am conscious that I have only touched the fringe of the subject, but I shall have succeeded in my object if I have given you some idea of the great forces that the engineer is called on to control and adapt in the course of his work. The little remaining space that I can spare I want to devote to a wonderful dream of the future.

Matter, as you know, is built up of tiny atoms, and these atoms contain within their minute size enormous quantities of energy. Of late years—chiefly through the discovery of radium—we have learnt a great deal about the constitution of these atoms, and men of science are now working to try and find out if they cannot devise a means for drawing upon this store of energy. Several men have written of it, but Professor Frederick Soddy, one of the leading workers on the subject, in his book on Radium, has given such a brilliant exposition of the possibilities that lie before man if he can but learn how to break up the atom, that I should like to quote his actual words. He has kindly given me permission to do so. Professor Soddy writes*:

* "The Interpretation of Radium," by Frederick Soddy.

"It is, indeed, a strange situation we are confronted with. The first step in the long, upward journey out of barbarism to civilisation which man has accomplished appears to have been the art of kindling fire. Those savage races who remained ignorant of this art are regarded as on the very lowest plane. The art of kindling fire is the first step towards the control and utilisation of those natural stores of energy on which civilisation, even now, absolutely depends. Primitive man existed entirely on the day-to-day supply of sunlight for his vital energy, before he learnt how to kindle fire for himself. One can imagine before this occurred that he became acquainted with fire and its properties from naturally occurring conflagrations.

"With reference to the newly recognised internal stores of energy of matter, we stand to-day where primitive man first stood with regard to the energy liberated by fire. We are aware of its existence solely from the naturally occurring manifestations in radio-activity. At the climax of that civilisation, the first step of which was taken in forgotten ages by primitive man, and just when it is becoming apparent that its ever-increasing needs cannot indefinitely be borne by the existing supplies of energy, possibilities of an entirely new material civilisation are dawning with respect to which we find ourselves still on the lowest plane—that of onlookers with no power to interfere. The energy which we require for our very existence, and which Nature supplies us with grudgingly, and in none too generous measure for our needs, is in reality locked up in immense stores in the matter all around us, but the power to control and use it is not yet ours. What sources of energy we can and do use and control, we now regard as but the merest leavings of

Nature's primary supplies. The very existence of the latter till now have remained unknown and unsuspected. When we have learned how to transmute the elements at will the one into the other, then, and not till then, will the key to this hidden treasure-house of Nature be in our hands. At present, we have no hint of how even to begin the quest. . . .

" Let us give the imagination a moment's further free scope in this direction, however, before closing. What if this point of view that has now suggested itself is true, and we may trust ourselves to the slender foundation afforded by the traditions and superstitions which have been handed down to us from a prehistoric time? Can we not read into them some justification for the belief that some former forgotten race of men attained not only to the knowledge we have so recently won, but also to the power that is not yet ours? Science has reconstructed the history of the past as one of a continuous Ascent of Man to the present-day level of his powers. In the face of the circumstantial evidence existing of this steady, upward progress of the race, the traditional view of the Fall of Man from a higher former state has come to be more and more difficult to understand. From our new standpoint, the two points of view are by no means so irreconcilable as they appeared. A race which could transmute matter would have little need to earn its bread by the sweat of its brow. If we can judge from what our engineers accomplish with their comparatively restricted powers of energy, such a race could transform a desert continent, thaw the frozen poles, and make the whole world one smiling Garden of Eden. Possibly, they could explore the outer realms of

space, emigrating to more favourable worlds as the superfluous to-day emigrate to more favourable continents. One can see also that such dominance may well have been short-lived. By a single mistake, the relative positions of Nature and man as servant and master would, as now, become reversed, but with infinitely more disastrous consequences, so that even the whole world might be plunged back again under the undisputed sway of Nature, to begin once more its upward toilsome journey through the Ages. The Legend of the Fall of Man possibly may indeed be the story of such a past calamity."

CHAPTER VI

ROADS—THE WORK OF THE ROMANS—A BLIND BRIDGE BUILDER—THE ROAD SURFACE—HISTORIC ROADS

A WOULD-BE wit has remarked on the folly of the farmers who select the muddiest portion of their field as the site of their gateway into it. The remark is of value as in an epigrammatic way it draws our attention to the importance of the road, and to the necessity of care being taken in its construction. The road is so common a phenomenon in our everyday experience that we are apt to under-estimate its importance, just as we habitually under-estimate the value of the bread we eat, the water we drink, and the air we breathe. Our indifference to the road, it is true, is less now than it was in the period intervening between the introduction of railways and the invention of the bicycle and the motor-car, for there are now few of us who have not realised the difference to our comfort between a well- and an ill-constructed road. Most of us, however, do not let our interest in the subject go beyond abusing the road authorities for their slackness in not troubling to repair the roads, and in the present chapter I want to show that the construction of a satisfactory highway demands the exercise of ripe knowledge and of carefully thought-out scientific principles.

Macaulay has well said that "of all inventions, the alphabet and the printing-press alone excepted, those

inventions which abridge distance have done most for the civilisation of our species." Not the least of the reasons for which we admire the Romans is because, as empire builders, they realised to the full the obligation that lay upon them to construct roads through the territories they administered. I would advise any boy who has not done so, and is fond of bicycling, to travel the length of the Great North (Roman) road as it stretches from London to Edinburgh. He will find in the passage much of interest to him—fine open country, mile upon mile of magnificent sea scenery near Berwick, and a perfect road from end to end. And as he travels over its surface he will not forget to be grateful to the old Roman legionaries who built so well that their work has defied the ravages of time. As Hugh Miller, the geologist, pointed out, the Roman legionaries at times thought more of military necessities than of the influence their roads were to have on the country. On occasions, though they drained many of the fens, their work was such that fresh bogs originated by their cutting roads through the forests. As Miller said when lecturing on geology, the felled wood was left to rot on the surface, small streams were choked up in the levels, pools formed in the hollows, the soil beneath, shut out from the light and the air, became unfitted to produce its former vegetation. But a new order of plants, the thick water mosses, began to spring up; one generation budded and decayed over the ruins of another; and what had been an overturned forest became in the course of years a deep morass.

We can forgive the Romans the damage they thus wrought, for in return in other parts they give us a network of splendid roads. The principles on which they built

were thorough and comprehensive. To mark out the road, ditches were built parallel to one another. The surface in between—you must remember that the Romans were driving their paths through wild territory—was excavated until a firm foundation had been reached. If a foundation was not available, one was constructed by driving in piles. On the basis thus laid were placed four layers. First, came a series of stones of a moderate size, called the *statumen.* Then followed the rubble or *rudus,* 9 inches of it, small stones rammed together and solidly bound with lime. On the top of it followed the *nucleus,* 6 inches thick, and this consisted of finely-broken brick, pottery and so forth, the whole again cemented with lime. Lastly, on these foundations the Romans built their surface of large blocks of the hardest stone they could find carefully fitted in together so that they should not lift under the influence of the traffic. When you watch the road-makers at work repairing one of these typical old Roman roads, with their carts of road metal and their steam-rollers, you would hardly imagine that it is on all this depth of foundation laid by the Romans that they are building the present-day surface.

The roads in Great Britain afford abundant evidence of the genius of the Romans, but Mr. Athol Maudslay, in a book he wrote some years ago—" Highways and Horses " —quotes an example of brilliant road construction that amazed me when I read of it. He writes :

" The grotto Pausilipo, near Naples, is a tunnel through which the high road from Naples to Pozzuoli passes. With this tunnel I am well acquainted, having frequently ridden through it on horseback ; it is cut out of the solid rock,

its length is two-thirds of a mile, and it is 60 feet in height, and wide in proportion. This tunnel is of great, but unknown, antiquity. Seneca, in his fifty-seventh epistle, complains of its length, darkness and dust. It is now well lighted, both by night and day, with lamps on either side, and is also fairly well paved; it was enlarged in the year 1557. Seneca speaks of it as follows: 'Nihil illo carcere longius, nihil illis faucibus obscurius.'"

Before we come to modern views and modern practice, I cannot pass over without mentioning the amazing engineering feat in road construction performed by Metcalf, a man who lost his sight at six years of age from an attack of smallpox. Incredible as it sounds, he would follow the hounds on horseback, was a first-rate judge of horses, used to make his way all over the country alone, and was a great constructor of roads. The problem was one day set him to build a road from Huddersfield to Manchester, and he found, to his dismay, that it had to pass over a bog. He was advised to dig down to a foundation, but refused. Instead, he cut a trench on either side of the intended road, threw the excavated material inwards, filled his trenches with heather, covered the track itself with heather, laid transversely, and on it built his road of gravel. So that it is to Metcalf, the blind road surveyor, that we owe the first idea of a floating road, an idea subsequently made use of by George Stephenson when he built his railway over Chatmoss.

The revival of road construction in England is associated with the name of Telford, but we will content ourselves with noting that his principle was to make a rough stone pavement, and on it to build a road surface. When

we come to MacAdam, whose name we still remember when we talk of macadamised roads, we are really in modern times. It seems a paradox to write that MacAdam applied to the roads the same principle that Smeaton applied to the building of the Eddystone Lighthouse, but such is the case. In both the essential idea was to devise a monolithic structure, one, that is, in which each portion would tend to aid in the strength of the whole, and in which any strain delivered to a portion would be borne by the whole. As Colonel R. E. Crompton has written: "Since MacAdam established the principle that if road metal be broken up into angular fragments not exceeding 2 inches in diameter, it can be pressed into a monolithic surface, and thus be rendered capable of spreading the weight of the wheel over a greater area of the foundation underlying it, all that was further required was to perfect the system by cheapening the process of breaking and consolidating the metal; but unfortunately, the road authorities of England have been lulled into false security by the many years of excessively light traffic on their roads during the period when they were used practically only for local traffic; so that they have used faulty materials and faulty methods of construction, the consequences of which the public are now reaping in the disintegration, dust and rough surface caused by the resumption of traffic. For this the motor-car is not really responsible. If the present amount of road traffic, which is due to the demand for fresh air and a sight of the country at week-ends, had to take place with horse-drawn vehicles, the nuisance to those resident near the main roads would be almost, if not quite, as serious as at present; for, although

the speed would be less and the dust raised less, a larger number of horses would be used, so that the badly constructed roads would be chipped and broken to an even greater extent than they are at present . . . It is unnecessary to labour the matter further than to point out that the present system of relying on water as a means of holding the top of the road in position cannot longer be tolerated."

Colonel Crompton, who was in charge of the Government steam train in India, and who also held an important post in connection with army transport in South Africa, is one of the great apostles in this country of the waterproofed road. It may be regarded now as an axiom that a road must consist of foundation and crust, and the chief points to be determined are the materials and arrangement that are best fitted for this double purpose. The ideal road of the future will consist of a foundation that must aim at being permanent, and of a surface layer that will from time to time be taken up and repaired. If this is to be achieved, it will be necessary for the surface to consist of asphalt or some such material, while the under layer will be composed of road metal carefully broken to gauge, and properly laid on a properly prepared subsoil. The essential, in fact, will be for us to approximate the conditions of the country roads to those of the towns, and to realise that, with the increasing use to which the roads are subjected, it will pay to have them properly constructed. To quote again from Colonel Crompton: "The author has in his mind one hole in the wood pavement near the Royal Albert Hall, which was noticeable eighteen months ago; it could have been repaired at any time at the cost of 10s.,

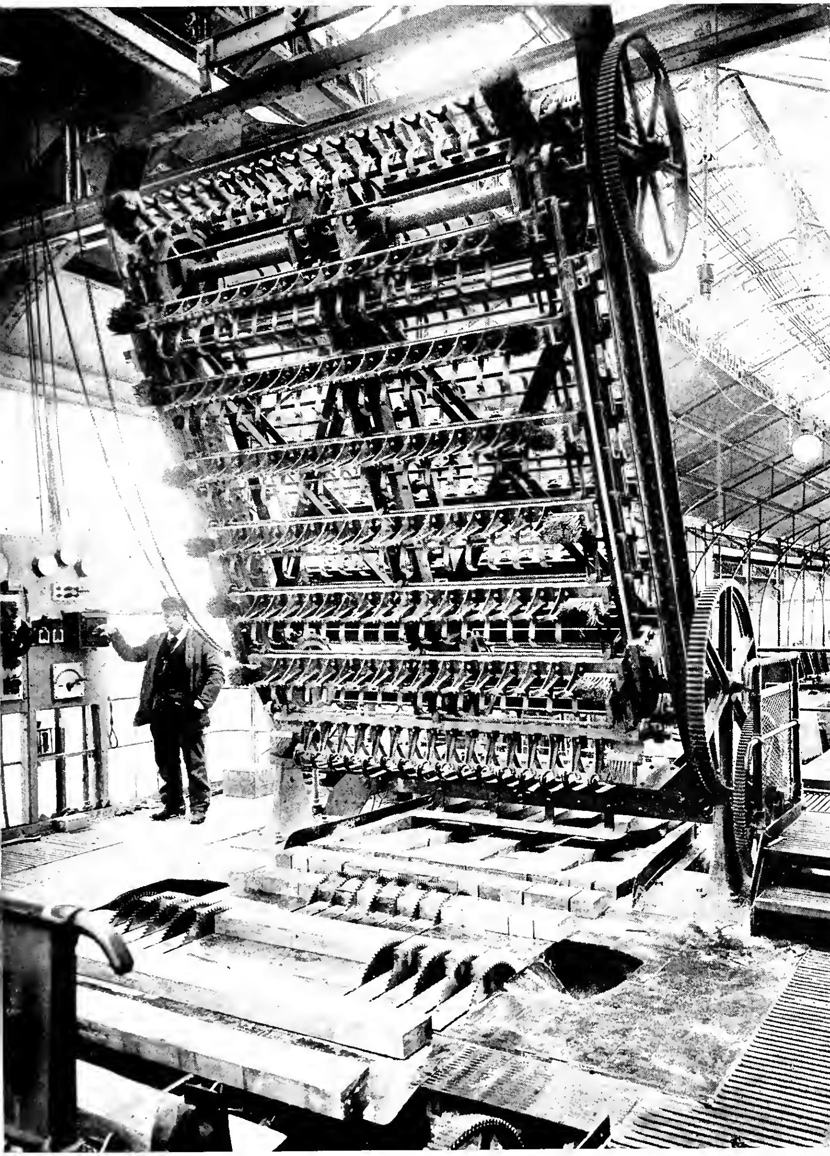


Photo: J. Boyer, Paris

SAW CUTTING WOODEN BLOCKS FOR CITY STREETS

View showing carriage lifted and work in progress

and it has damaged vehicles of all kinds to the extent of possibly several hundred pounds."

The evil of the water-bound road lies in the fact that in most cases the road is too dry, so that the finer material is loosened, moved, and eventually lifted by the wheels of passing vehicles and blown away by the wind in the shape of dust; or in wet times these same particles form, with the excess of water, a fluid mixture which acts as a lubricant to the larger pieces of road metal, allowing them to roll on one another and grind themselves into powder, instead of retaining them firmly in their place.

It would take us too far afield to discuss several of the problems that lie before the road engineer. One of his aims will be to reduce what is known as the camber or slope of the road, designed to facilitate drainage, and this when roads are waterproofed will be an easy matter; it has long been his duty to do all in his power so to design the run of the road that it shall follow the easiest possible gradient. A neglect of this principle made the now-condemned Southwark Bridge useless for traffic, as the slope was too steep for it to be practicable for horses to draw heavy loads to the bridge level, and we have little sympathy to-day with the Indian Department, which, to the remonstrance of an executive engineer who complained that the slope of 1 in 30 to a bridge was so steep that it caused a block in the traffic on the road, replied that the true remedy was to improve the breed of cattle in the country. Elaborate trials of materials and construction have still to be made. But to show the intricate machinery that is to-day employed in the preparation of the wood blocks used on the London streets, I am including a photograph of one of those

gigantic machines. For our asphalt we have gone even to remote Trinidad, and that you may appreciate the way in which the pitch that is its basis may be found in Nature, I am quoting the account that Mr. Clifford Richardson wrote of it in the pages of the *Popular Science Monthly*: "The surface or deposit of the lake is not a uniform expanse. It is grassy along the edges, and becomes free from vegetation at some distance from the centre. Shrubs and small trees occur in a few cases, known as islands. The patches move from place to place with the movement of the pitch at the surface. The main mass of asphalt is a broad expanse of pitch made up of separate areas of irregular outline, but at times quite circular, which are separated by channels filled with rain water, which prevents their coalescence. The boundaries are depressed and the centres of their areas are always somewhat elevated above the edges, that is to say, they are mushroom-like. The origin of the separate areas evidently lies in the constant movement of the crude material, due to the evolution of gas at the centre, from which point the pitch rolls over towards the edges. This is shown by the fact that pieces of wood which emerge erect at the centre are gradually carried to the circumference, their deflection from the perpendicular increasing as the distance from the centre increases. At the channel they topple over and are again engulfed in the pitch."

I have devoted considerable space to the question of road surface construction, because that, after all, is the aspect of the question with which most of us are more nearly concerned. When we try to review the question in a broad way, it comes to us as rather a surprise to realise

that road-building, apart from the wonderful activity of the Romans, has been almost entirely a work of modern enterprise. When Mr. MacGeorge wrote an account of the ways and works in India, he brought home the strangeness of the idea of making roads in the beginning of the last century by an anecdote relating to Lord Elphinstone at the time when he was appointed to be Governor of Madras. Elphinstone proposed the construction on a comprehensive scale of new roads in the Madras Presidency, and the idea appeared so ridiculous to the man in authority at that time that one member of the Council wrote home a complaint to England that "the silly young nobleman actually talks of making roads." On another occasion, when the Government sent out circulars asking the district collectors to send in a statement of what district roads they considered necessary to develop the resources of the country, among the replies received was the amazing one from a collector that in his district "no roads were required, because the people there did not use carts, but carried everything in panniers on the backs of bullocks."

In the time that has passed since these remarks India has made good in a marvellous way. She has furnished examples of road construction, carried out in circumstances of amazing difficulty, when the engineers have had to contend both against the obstacles placed by Nature in the shape of mountainous country and the ill-will of the tribes through whose territory the road has had to be cu As often as not the work has been carried out under conditions like those that attended the rebuilding of Jerusalem, where the men had to be at once both warriors and masons. The Grand Trunk Road that stretches in practically an

unbroken line from Calcutta to Peshawar, traversing a length of 1,500 miles, reaching close to the Khyber Pass of Afghanistan, has long been one of the world's famous roads. It is the road that Mr. Kipling has immortalised in "Kim," and its construction by British engineers is one of the title-deeds by which we hold the Indian Empire. This road takes us back to the days of the great Empire-builders, for it was under the rule of Warren Hastings that the scheme was first inaugurated. But the father of the road was Lord William Bentinck. Throughout its length the road was well drained and well metalled, raised everywhere above the height of floods and inundations. Timber trees were planted along the side to give shade. Halting-places or encamping grounds were arranged at suitable intervals for the convenience of merchants and goods, and at every ordinary stage for troops on the march; enclosures for shops, and open encamping grounds, marked off and kept clear from cultivation, were established. Rest houses for the better class of travellers were also provided at distances of 10 or 15 miles along the road. The difficulties met with were of no light order, for you must remember that the engineers were working under conditions of which they had no experience, and were forced to build bridges that would withstand the force of raging torrents. One of the bridges they built, which went over the Lelajaum River, consisted of twenty-six 50-feet arches, and the builders were not men who could draw either on highly skilled labour or on expert advice. They were engineers of the road, men who had to wrestle with their own problems for the most part alone, and to find a way out for themselves. There are other ways of crossing a river than by bridging

it, and one of the devices to which recourse was often had with the larger rivers was to build a causeway in the river-bed. Often enough in India the great rivers run almost dry except for a few months in the year, and in such cases the approaches to the river-bed were cut down to an easy slope and a causeway was driven across it, care being taken to make it strong enough to prevent it being carried away in the period of the floods. I am indebted to Mr. MacGeorge's work for the account of the method employed in the case of the causeway that runs across the Sone, near Mirzapur. This was 11,450 feet long, or over 2 miles in length. The paved roadway, 16 feet in width, was formed of stone slabs, 9 feet to 7 feet long, about $1\frac{1}{2}$ feet broad and 1 foot thick. A foundation was provided by first driving two parallel rows of common junglewood piles to a depth of about 15 feet, for the purpose of supporting bamboo frames and mats temporarily to hold up the sides of the sand excavation that was to be made between the two rows of piles. The sand being excavated and a trench dug of the requisite depth and width, a layer of gunny bags, filled with concrete made of river shingle and lime, was set closely packed together over the whole bottom of the trench. On these bags a layer 2 feet 6 inches thick of rubble stone was laid set in similar concrete, on which the long paving stones forming the causeway were placed crossways in alternate long and short lengths so as to break joint. The joints of the stones were then pointed and filled in with good hydraulic mortar, and the surface of the causeway finally levelled, but left rough enough to afford a secure foothold for draught animals.

The constructors of the Grand Trunk Road have long

ago gone to their rest, but when Mr. E. F. Knight joined Colonel Durand's expedition against the raiding Hunza-Nagars, in 1891, in Kashmir, the experiences he had there enabled him to give those at home an account of the enterprise, courage and resource with which the work of road-building is still carried out by the road-builders in India.

Mr. Charles Spedding was Mr. Knight's fellow traveller to Kashmir, and was engaged on the construction of some strategic roads in the country, and when Mr. Knight decided to publish his experiences in book form, under the title, "Where Three Empires Meet," he included an account of several incidents in connection with this work of road construction. The old road leading from Srinagur to Gilgit was a rough track, so narrow in the more precipitous parts that two mules meeting could not get by each other; it was almost impassable for a mountain mule battery, and it was quite the usual thing for baggage animals to slip off the dangerous path and be lost in the torrent beneath.

The suffering caused by the old road was pitiful. Unfortunate coolies would be dragged from their homes in different parts of the State to carry loads over it, never to return, but to die of cold or starvation on the roadside.

Mr. Spedding had need of all his powers of organisation to look after his gang of 5,000 native navvies. The men could not live in the country, for it was barren and desolate, and all supplies—food, clothing and so forth—had to be carried over the passes, and when the work was projected it was still a matter of uncertainty whether sufficient food could or could not be brought through. Where the old road would zigzag up the hill-side, the engineers would blast a gallery along the cliff face. This is Mr. Knight's

comment on a portion of the route: "The line of the new road will be somewhere between two native roads. The engineering difficulties presented here are very great, and it must be almost impossible to construct a road that will not be repeatedly swept away by the falling rocks, while the loose mountain side, even rocky as it is, affords the least secure of foundations. It was anticipated that there would be numerous accidents among the navvies employed on this section of the road while working on this perilous mountain, and I heard that upwards of 30 men had been killed here before I left the country, having been struck by falling rocks, or precipitated into the abyss by the crumbling away of their foothold."

In those out-of-the-way parts of the world a road-engineer has to perform many curious tasks. He may be called upon to administer justice of a rough-and-ready order. A strange occurrence of this sort arose from the claim made by a native that some of the Afghans working on a section of the road had forcibly seized a sheep, and had stolen out of a house a valuable olive-wood casket, 20 rupees, and a robe of honour. The engineer ordered accuser and accused to come before him in the evening. One of the gang was suspected, and before night representatives of the gang concerned came to the engineer, asking him to allow them to settle the matter among themselves, according to their own custom, undertaking that the property should be found. A deep hole was dug in the ground, and as soon as it was quite dark every man of the gang in turn went alone, unobserved of the others, and poured into the hole his lapful of earth. The next morning the villagers were instructed to search in the loose earth,

and there they discovered the casket, the money, the robe of honour, and the price of the sheep, no man knowing who it was that had restored the property.

For an account of the campaign itself, where, with scarcely twenty British officers engaged, three won the Victoria Cross, and a fourth was awarded the Distinguished Service Order, I must refer you to Mr. Knight's book. Our connection with it at the moment is because Mr. Spedding transferred himself and some of his men from the Gilgit road work as a sapper and miner corps. This is the appreciation that Mr. Knight, who you must remember is an experienced war correspondent, felt justified in writing of the services rendered during the campaign by the road engineers:

"Spedding had volunteered to place himself and his men at the disposal of the Government for the purposes of this expedition. Their work had been most arduous, their conduct under fire and their discipline had been admirable. It would be difficult, I imagine, to mention an instance since the Mutiny days of such splendid service rendered by civilians in time of war. Spedding, with his talent for organisation, and his great experience in the transport and the feeding of large bodies of men in a desert country hundreds of miles from the base, was an invaluable aid to Colonel Durand. This good work was done in a patriotic spirit, not for pecuniary remuneration, but at a considerable cost to Spedding himself. Such men deserve well of their country."

The road-engineer is faced with many of the same difficulties that beset the railroad surveyor, and in connection especially with railway construction the men who go out into the world to survey a line of route must

often carry their lives in their hands. Their ingenuity has continually to be exercised to provide an escape from the difficulties presented by material conditions. Tunnels must at times be cut through the rock where a suitable way or road cannot be made, and at times, as at the Simplon Pass, a special channel has to be built to carry a stream right over the head of a road. In such mountainous districts as the Alps shelves have to be made so as to enable the avalanches of snow or rocks to shoot clear over the road and pass harmlessly into the depths below. In the Stelvio Pass, the loftiest road in Europe, that reaches 9,000 feet high and serves as a passage between Austria and Italy, the road can only reach the summit by a series of zigzags, and even then it is only open to traffic for a few months in the year. In Paris they have widened one of the roads, the Rue de Rome, by the curious expedient of fitting up concrete brackets, and running the road on these supports. Viaducts and bridges have to be thrown across ravines, waterways must be bridged, morasses crossed, and the whole work must be done so that the gradient on the road is maintained at a moderate pitch, so that distances are not unduly drawn out, and that the needs of the community are adequately served.

Curiously enough, it is to military science, above all other considerations, that we owe our great roads. It was war that inspired the Romans to ensure rapid means of communication ; it is, above all, for purposes of war that we have driven roads to the outlying frontiers of India. That war brings horrors in its train is a fact beyond question. When we try to enumerate the advantages it also entails it would be well for us to remember that we owe to it the excellence, nay the very existence, of many of our roads.

CHAPTER VII

TOWN PLANNING—THE CHOICE OF BYZANTIUM—THE DESIGN OF AUSTRALIA'S CAPITAL

Town planning is one of the oldest arts, and, like most of the old arts, its origin is lost to us. It can be traced back to the Greeks, for it is possible to draw a most interesting map of the shores of the Mediterranean showing how the various great cities of Greece would send colonies out all over the land under their separate leaders, to some suitable site, where their city would be built. You must all remember how the colony of Byzantium was founded, with the story of how the oracle said that the founder should take his men with him and search the land until he came to a city of the blind. One cannot help feeling that the leader had instructions rather more definite than these to go upon, and that it was under wise direction that, on reaching Byzantium, he selected its site, saying that this must be the place of which the god had spoken, for the men who had built a city opposite must surely have been blind in not seeing the superiority of the site of Byzantium to their own.

The finest account of town planning is unquestionably that given by Virgil of the building of Carthage in the "Æneid," and, reading between the lines, there is no great difficulty in seeing that great care was taken in the ordering of the city as a whole, and when you come to think

of it, it is natural enough that Virgil, as a Roman, should have been struck with the idea, for in their numerous campaigns the Romans were always at work on town-planning, their nightly camp being constructed to a most elaborate regular scale.

In the ordinary course, however, towns have rather grown than been planned, and in London especially we see the nuisance that has been caused to us by the haphazard way in which our ancestors did their building. Now, at large expense, we are forced to take on street widening schemes, and if you go down Fleet Street at present you will see many of the shops boarded up and in course of reconstruction, so that they can be set back a few feet to provide more room for the incessant volume of traffic running east and west. The imagination is staggered when you come to think of the cost of the whole Kingsway improvement. It is only a few years now since the site of Kingsway was covered with a dense network of streets, where the houses had grown up according to the caprice of the builders. The London County Council, realising the need of a great artery to join north and south, have had a very expensive job of it in providing the site of what is now one of the finest thoroughfares in London.

We and the world at large have learnt our lesson, and the architects and engineers have found a new field for their activities in scientific town planning. Just think what a wasteful thing it is to have a vast factory set up on an expensive town site! The manufactured article has to bear the cost of the heavy rents and rates charged for the site; the workmen, too, have to be paid a high wage, of which they do not get the advantage, because in their

turn they must pay high rents for their houses, and big prices for their food and other necessaries, to pay for the rent of the shopkeepers, and so the whole thing goes on in a vicious circle. The children, again, are deprived of their rightful heritage of light and air. It is reasons of this sort that have led to such town-planning schemes as the Garden City of Letchworth, where whole industries have migrated out into the country, and where all the people can live in conditions of decency and comfort. The whole thing has been made possible through the engineer, partly because he has given us the chance of cheap transit through the railways, and partly because of the facilities of cheap power that we now enjoy. With the growth in electric energy, the future of garden cities is a rosy one, and it is a matter for satisfaction that machinery, the factor above all others that helped to force our people into the larger towns, should now be the factor that makes it possible for them to escape again back into the country.

It is rather, however, of town planning on a more comprehensive scale that I want to write. It is ancient history now that the capital city of Washington in the United States was definitely planned; only last Christmas we were reading of the transference of the central government of India to Delhi, where the architects and the engineers had to plan a new town in India's historic capital, and now, just as I was preparing to write this chapter, the news has come through of the laying of the first stone of the commencement column of the federal capital of Australia.

The laying of the stone is one of the landmarks in the history of a great country that is marching on in a steady stride to become one of the mightiest nations of the

world, and, appreciating the importance of this event in imperial development, Mr. Borden, the Premier of Canada, cabled to Mr. Fisher, the Australian Premier, on behalf of the Government and people of Canada, tendering his warmest congratulations on the foundation of the Federal capital, and his earnest wishes for the continued and increasing development and prosperity of the great sister Commonwealth. "Though far removed," says Mr. Borden's message, "as miles are measured, we are very close to you in the ideals and aspirations of democracy, and in the common tie which binds the two kindred nations in a firm allegiance to our great Empire."

The laying of the stone was carried out under most auspicious conditions on the morning of March 12th, in the presence of Lord Denman, the Governor-General, and Lady Denman. The first stone of the commencement column of the projected city was laid by Lord Denman, the second by Mr. Fisher, the Prime Minister, and the third by Mr. King O'Malley, the Minister for Home Affairs. The name selected for the capital was kept secret until Lady Denman drew it from a casket, and said: "I name the capital of Australia 'Canberra.'" The announcement evoked a storm of applause, as there had been much controversy over the suggested name Myola and other proposals.

The whole history of the planning of this federal city is of interest, for the architects of the world were invited to submit their plans to the Australian Government for it. By an unfortunate disagreement as to the terms of the competition, the proposal was frowned on by the architectural authorities in this country, and it is curious to note that the winner of the prize, Mr. W. B. Griffin, a

35-year-old native of Chicago, did not hear of the offer made until five months after the event. He only had two months on his plans, and all his raw material was the virgin site, a mountain plateau, of an area of 900 square miles, in the Yass-Canberra district of New South Wales, lying in a triangle formed by three mountains.

The site of the city itself has an area of 25 square miles, and is to be built for a population of 75,000, with facilities provided for an indefinite increase in population, while the three mountain peaks in the district will form a magnificent background to the city itself.

Mr. Griffin's design, which, of course, had to take into consideration all the special conditions of the site, is very ingenious. It consists of three centres for the inner city, and of five for the outer. In the inner portion there are to be Government, municipal and mercantile centres, from which boulevards will radiate, while the outlying district will contain three agricultural centres, a manufacturing centre, and a suburban centre.

A great effort has been made to ensure that the noise of the city shall be kept away from the residential quarters. The houses built on the streets lying between the great radial centres are to enjoy quiet and secluded park-like atmosphere, and at the same time will never be further removed from the main business thoroughfares and the lines of local transportation than four blocks. The city is only to have a single railway through it, and all the freight yards, freight depots, transfer facilities and warehouses are to be placed outside the city limit.

It is one of the architect's principles that the railroads entering large cities mar their beauty, and are often flanked

by poor districts. In the City of Canberra, Mr. Griffin believes that the railway will actually beautify the city, and it has been so arranged that it will run semi-circularly round the business centres without cutting the main business streets anywhere.

There is one other aspect of the city that demands our attention. It is proposed that the material of which it is to be constructed shall be reinforced concrete, on the ground stated by Mr. Griffin, that it is the "newest, cheapest, most plastic and variable single medium yet introduced into construction." In a later chapter we shall see the variety of uses to which reinforced concrete can be put. That it is the substance favoured for the capital city of Australia is an indication of the way in which it has sprung into general favour, and will go far to increase the popularity of concrete as a building material all over the world.

Town planning is, in its latest aspects, a modern development of engineering. In it, the engineer—for the architect, after all, is an engineer—has offered him fine scope for the display of artistic talent, and it may be that as a result of people living in artistic surroundings a check will be placed on the spirit of materialism, and that the engineer will have an important part to play in this connection, too, as a factor in the humanisation of the race of man.

CHAPTER VIII

LONDON—ITS WATER SUPPLY, ITS SEWERS, AND ELECTRIC SERVICE

LONDON, with its population of 7,000,000, presents to the engineer a variety of problems that is, I should imagine, unequalled in any area of similar size throughout the world. I have had to refer to it in the chapter on town planning. We can see in the chapter on the work of a great contractor that a London job—the construction of one of the great sewers—is numbered among his mightiest undertakings, and, in fact, you will find references to the metropolis of the Empire scattered throughout the book. No wonder either when you start to think rightly of London. Look at the great railways running into it on north, south, east, and west, at the bridges that span the restless waters of the Thames; at its great wharves, its network of tubes and tramways, the traffic of its streets, the power required to warm and light its houses, its shops and its places of amusement, its big factories, and the vast buildings that it requires to enable it to realise the proud position of being the mart of the world. To describe the engineering work of London would take up a whole volume, and even then there would be other volumes left to be written. I propose, therefore, only to touch on one or two aspects of the problem, and, as a start, to say something of the great waterworks at Chingford

that were formally opened in March of this year by the King.

With the felicity of expression that has long been recognised as an attribute of the Royal Family, the King when he went down in State to Chingford to open the new waterworks that have been constructed replied to the address presented by the Metropolitan Water Board as follows :—

" The Queen and I are very glad to be present to-day to inaugurate the Chingford reservoir, and to witness the completion of this part of your enterprise. It is interesting to recall the association of my ancestor with the inception of London's water supply when the New River was formed to carry the springs of the River Lea to the heart of the City. The accomplishment of this arduous task, in the year 1613, was largely due to a distinguished Welshman, Sir Hugh Myddelton, whose dauntless nature overcame unending difficulties and opposition ; and the first official act of his brother, Sir Thomas Myddelton, who was elected Lord Mayor of London the same year, was to perform a ceremony such as I have undertaken to-day.

" The citizens of London will do well to remember that after three centuries they still owe a debt of gratitude to the Lea for the remarkable purity of their water supply. Since the days of King James the First the problem has become immeasurably greater with the constant widening of London's boundaries and the vast increase of her population. The large sums which the Metropolitan Water Board have found it necessary to spend in new works bear witness to the magnitude of their task, and it is easy to realise the heavy burden which falls on those responsible

for the policy and administration of such great undertakings.

"You are justly proud of this reservoir, which is a splendid monument to the energy of your officers, the skill of your engineers, and the industry of your workmen. We congratulate you warmly on the success of your labours, and we shall ever follow with interest the continued progress of this important undertaking, so vital to the health and well-being of my Empire."

As soon as he had ceased speaking, the King went to a table at the front of the stand, and, pressing a small gold switch there, started an electric current, which set the pumping machinery going. At the same time he used these words: "I declare this reservoir open, and name it King George's Reservoir." Immediately afterwards, one of the five great iron mouths at the top of the cascade steps belched forth a flood of water, and a minute or two later the others were doing the same, producing a foaming, tumultuous cataract, which the Royal visitors, and, indeed, everybody else, watched with intense interest for a considerable time.

In the address of the Water Board presented to the King it was pointed out that in the furtherance of the purpose of meeting the ever-increasing demands of the metropolis, and parts adjacent, for the copious supply of pure and wholesome water, the Board had expended on new works at Chingford and elsewhere a sum approaching to £3,000,000 since they assumed the control of the water undertaking in the year 1904, and additional works, involving a further cost of £1,600,000, would shortly be commenced in the valley of the Thames. It is difficult from

Photo supplied by the Metropolitan Water Board

FIVE HUMPHREY PUMPS WORKING AT CHINGFORD RESERVOIR

figures to get any idea of the magnitude of this and other undertakings which the Water Board have carried through.

Since the date when the first sod was cut, on April 11, 1908, the work for the reservoir proceeded apace. No fewer than 1,000 acres of land were acquired, of which 416 acres are occupied by the water-area. The reservoir has an embankment 4½ miles long, formed from the material excavated from the reservoir, and containing more than 2,000,000 cubic yards of earthwork and 250,000 cubic yards of puddle. So vast are the forces dealt with, that it has been partly divided by a breakwater, in order that in stormy weather the waves may not rise to destructive proportions. The reservoir itself has the tremendous capacity of 3,000,000,000 gallons, and the supply is derived from the River Lea and the Lea Navigation. The water is taken up by five huge pumps when the river is in a state of high flow and as soon as the turbid flood-water has run to waste, and stored away. In ordinary circumstances one pump only will be brought into use. The pumping machinery, all told, is capable of lifting more than 200,000,000 gallons per day. The pumps are of a new type as regards London waterworks. Each one is really an explosion chamber, working on the internal combustion principle, and blowing, not pumping, the water into a tower, whence it passes into the reservoir. It may be added that to accomplish this work, it has also been necessary to divert the course of the River Lea for a distance of 3 miles, and to construct a new channel 55 feet wide. For the moment the new reservoir ensures to London what has been aptly described as the "life blood of the City"—an astonishing feat, when one remembers that the Water Board have to meet the

needs of more than 7,000,000 people to-day, each of whom requires 32 gallons per day (36 gallons in summer), or a barrel of water per head for every man, woman, and child. Not less than 90,000,000,000 gallons of water were distributed in the year 1911–12. But what of the future? Neither the Thames nor the Lea is inexhaustible, and although the former river will be used to greater advantage when additional reservoirs are at work, by taking in its flood waters, there may come a day when London has to find another gathering ground to meet her insatiable needs. More than once the question of Welsh water for London has been raised, and even with the magnificent resources made available by the Chingford reservoir, it may be expedient, before many years are gone, to cast the eye abroad in order that the old lesson of history may not be repeated—and London find itself again growing faster than its supply of water.

I have already pointed out, you may remember, that the pumps for the Chingford reservoir—they are Humphrey pumps, by the way—are of peculiar type. As to their working, we have in the photograph a sufficient indication for us to be content with the short description I have given of them. The story of their construction, however, illustrates that the engineer must always be prepared to back his opinion. When Mr. Humphrey was first approached by the London County Council, he had only built one of them with the relatively slight strength of 35 horse-power. He at once promised to jump from this to between 200 and 300 horse-power. The Water Board took him at his word, and gave him their contract for the work, but before doing so they insisted on his backing his

opinion to the extent of £20,000, an amount that he was to forfeit if his pumps proved unsuccessful. Events have shown that the inventor was justified in his self-confidence, for the large pumps when completed behaved exactly according to the prophecies he had made, and they are now being sent to pump water throughout the different countries of the world.

At the time of the opening of the new reservoir, the *Morning Post* published a most interesting sketch, illustrating the point that London has continually been in danger of outstripping its water supply, and the article shows this aspect of London engineering so clearly that, with the permission of the editor, I am quoting it as it stands:

"Water-supply and development," the writer said, "have gone hand in hand through the centuries. For a time London folk were content to use the water of the Thames—which was more 'silvery' than we can ever hope to see it again—to rely on streams, such as the Holbourne, the Tyburn, or the Walbrook, or to sink shallow wells in the porous subsoil, notwithstanding that the water from the last, clear and sparkling as it might appear, was sometimes a source of the worst form of contamination. Our forefathers held in great esteem the pump by the churchyard wall of St. Giles-in-the-Fields until the water became infected and cholera ravaged the immediate neighbourhood. The growth of London was, in fact, restricted to the areas possessing water-bearing strata, and it was not until conduits brought water from a distance that the clay districts of Camden Town, Kentish Town, and the like supported a population. The first of these conduits

began its course at Tyburn, and by 1238 no fewer than nine pipe-lines had been laid from this brook to the City. The old wooden pipes were formed of tree-stems drilled through the centre and cut into lengths of 6 feet, and within living memory some of these relics have been dug up in Piccadilly. Many conduits were set up in various thoroughfares, and one of the most famous was that of Chepe, which was not always devoted to the distribution of water. 'This year, 1273–4,' says the Anglo-Saxon Chronicle, 'came King Edward I. and his wife from the Holy Land, and were crowned at Westminster on the Sunday next after the feast of the Assumption of Our Lady; and the Conduit in Chepe ran all the day with red and white wine to drink for all such as wished.' Many wished. Another famous conduit, one of many, was the Tunne of Cornhill, 'a cesturne for sweete water,' as Stow tells us, 'conveyed by pipes of leade from Tiborne,' and occupying the site of an old house of correction where night walkers had been kept in durance. The conduit at Holborn Circus was reconstructed in 1577 by Mr. William Lamb, who gave his name to 'Lamb's Conduit Fields' of two centuries ago, and the Lamb's Conduit Street of the present day. But although many people drew their water from the standards at their door or the public fountains, there still remained plenty of work for the 'tankard bearers,' or 'cobs,' who conveyed the liquid from door to door in a cone-shaped barrel, holding about 3 gallons, which was carried on the shoulder.

"But in those old days, as now, London was growing faster than its water supply, and in 1581, a Dutchman named Peter Moryce obtained from the Lord Mayor a

lease for a term of 500 years, at an annual rental of 10s., authorising him to erect a pumping-engine within the first arch of London Bridge. This 'artificial forcier,' as Stow calls it, was the marvel of the age. By its means, and that of machinery erected in the second arch of London Bridge, Thames water was conveyed 'in pipes of leade over the steeple of St. Magnus Church, at the north end of London Bridge, and thence into diverse men's houses in Thames Streete, New Fish Streete, and Grasse Streete, up to the north-west corner of Leadenhall, the highest ground of all the citie, when the waste of the maine pipe rising into this standarde (provided at the charges of the citie) with four spoutes, did at every tyde runne (according to covenant) foure wayes, plentifully serving to the commodity of the inhabitants near adjoining in their houses, and also cleansed the chanels of the streete towarde Bishopsgate, Aldgate, the bridge, and Stocks market.' The waterworks remained in the hands of the Moryce family until 1703, when they were sold for £38,000 to a number of citizens, who formed a company, and obtained a lease of the existing conduits for £700 a year. It was not until 1822 that the company was dissolved.

"Long before that day, however—in 1609, to wit—Hugh Myddelton had appeared. London, with a population of over 150,000, was at its wit's end for water, and the bold and adventurous Welsh goldsmith embarked, almost single-handed, on the now famous New River scheme for bringing water to the northern parts of London from the springs of Chadwell and Amwell, and other districts of Hertfordshire, by a route 38 miles long. 'The dauntless Welshman stept forth and smote the rock, and the water flowed

into the thirsting Metropolis.' But not until he had fought down an army of opposition—landowners on the line of route, powerful interests, and the prejudice which, as Goethe said at a later date, resists everything that happens to be new, 'and thus a new truth may wait a long time before it can make its way.' Myddelton had sunk his own fortune, and failure was threatening, when he found a friend in King James I., who in this respect was wiser than he knew, and gave the engineer his hearty support, the condition being that his Majesty should pay half the cost of the work, and receive a portion of the profits. Michaelmas Day, 1613, saw the huge undertaking completed, and the New River opened at its 'head,' in Islington, with all the pomp befitting the occasion. Three score labourers, carrying symbols of their work, marched round to the tune of the drum, and then stood at attention while the 'speech' by Thomas Myddelton was pronounced:

'Long have we labour'd, long desir'd and praid
For this great worke's perfection, and by th' aide
Of Heaven and good men's wishes, 'tis at length
Happily conquer'd by cost, art and strength;
And after five yeares deere expense in dayes,
Travaile and paines, besides th' infinite wayes,
Of malice, envy, false suggestions,
Able to daunt the spirits of mighty ones
In wealth and courage, this, a worke so rare,
Onely by one man's industry, cost, and care,
Is brought to blest effect, so much withstood,
His onely aime, the cittie's generall good.'

"At the conclusion of the speech—there was much more than this—'the flood-gate opens, trumpets giving it

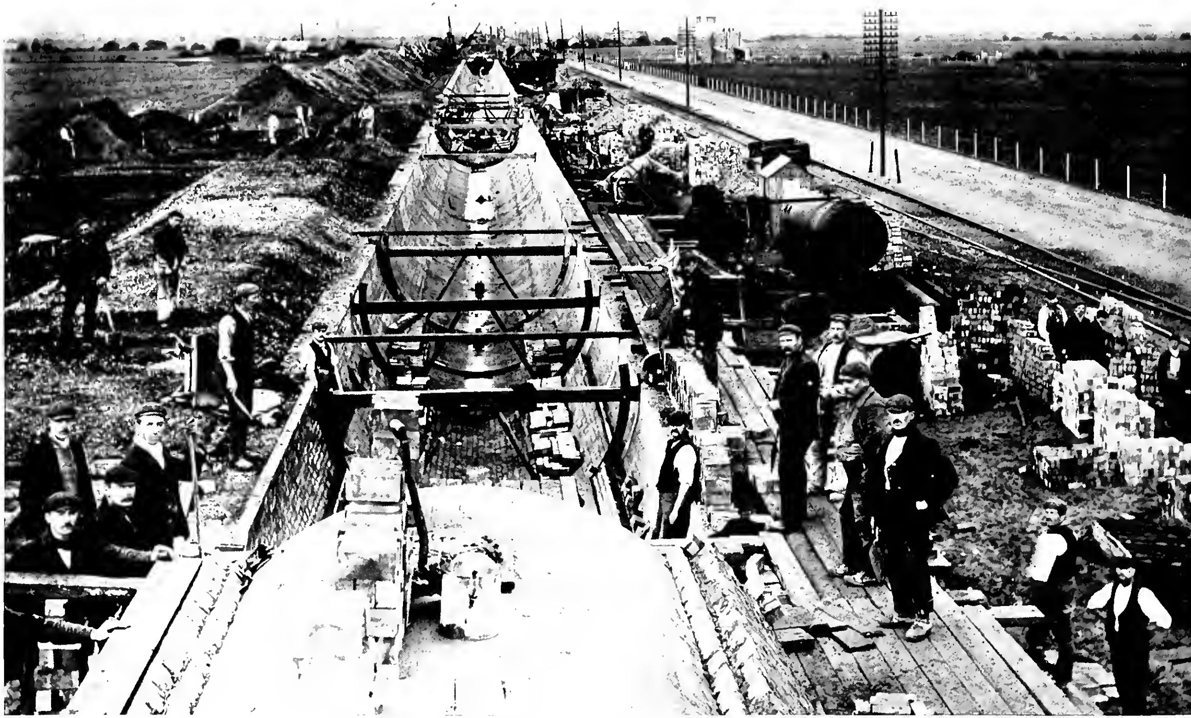


Photo: Ernest Milner, Wandsworth, S.W.

AT WORK ON A LONDON SEWER

Constructing the pipe in the open

triumphant welcomes, and for the close of their honourable entertainment a peale of chambers.' "

The later history of the New River is an old story now —how the citizens, accustomed to get water for nothing, objected to use the New River supply, and were compelled to do so by measures which checked free competition; how twenty years elapsed from the day of opening before any dividend was paid; how prosperity increased, until by the middle of the nineteenth century the dividend was at the rate of £850 per share, and an undivided Adventurer's share was sold in open market for as much as £94,900; how other water companies were established, and yet, in spite of their miles of mains, no fewer than 80,000 houses, containing 640,000 inhabitants, in London were unsupplied by water in 1850; and how, less than ten years ago, the whole of the water supply of London passed into the hands of the Metropolitan Water Board, at a cost of a little under £40,000,000.

Great as is the problem of the water supply of London, that of arranging for its efficient drainage is as great or even greater. When you pull up the waste pipe of your bath in the morning, you hardly realise that the water you have then used has to be carried away 15 miles or more underground before it can be delivered into the river Thames, to be taken away to sea by the channel provided by the arch-engineer of all—Nature. I have now before me the report on the main drainage of London that was submitted to the London County Council last year by Sir Maurice Fitzmaurice, the chief engineer to the Council. In the old days, as he points out, the sewers were mere trenches, either making use of, or being designed to take

the place of, the natural streams and ditches. It was not until 1732 that the River Fleet, which at one time was a navigable stream, was covered in and by Act of Parliament formed into a sewer below Holborn. In the early days the great London drains were devised merely to carry off the surface water; but with the abolition of the cesspool they have had both to deal with this and also to carry off much of the mud from the streets and the various material that the ordinary house drains are required to accommodate. Briefly, the system may be summarised as consisting of allowing the sewage to run down in vast main drains—constructed for the most part, as my illustration shows, on the principle of the London Tube tunnels, as far as possible by the force of gravity to the great pumping stations that lie on the banks of the Thames to the east of London. There it is treated chemically, so far as is possible to precipitate all solid matter, and as a result of the action of the huge pumps employed, the water is enabled to flow into the River Thames by the action of gravity at Barking and at Crossness. The sludge, as the precipitated matter is called, is loaded into special steamers and carried out far down the Thames estuary to Black Deep, where it is deposited over an area of 8 or 10 miles. These sludge steamers are peculiarly constructed, so that the bottoms of their great tanks can be opened while they are at sea and the sludge dropped from them, the heavy mechanical work that would otherwise be necessary being thereby avoided. The quantity of sewage that is disposed of in this way amounts to between 8,000 and 9,000 tons a week.

We are apt to think that it is our generation that has

Photo: Ernest Milner, Wandsworth, S.W.

CONSTRUCTION OF A LONDON SEWER

Tunnelling under the City

hit on the brilliant idea of utilising this vast quantity of sewage, but, as Sir Maurice Fitzmaurice shows, the idea was very much more prevalent fifty years ago. The view generally held now is that such schemes are impracticable except where there are considerable quantities of suitable commercial material admixed, as, for instance, at Bradford, where the sewage, owing to the woolcombing industry, is very largely charged with grease. To show that plenty of thought has been expended on the problem, I may mention the scheme, to which Parliamentary sanction was given in the Metropolis Sewage and Essex Reclamation Act, whereby it was intended to reclaim the great tracts of low-lying sand, known as the Foulness sand, and to utilise the sewage for purposes of fertilisation. The works were actually commenced, but the prospects were not sufficiently encouraging to attract investors, and the undertaking was abandoned, the £25,000 deposited with the London Board, as security that the works should be completed, being the only money the ratepayers of London have ever received in respect of their sewage. Another scheme was to pump the sewage and sell it as agricultural manure to the farmers in Essex. An experiment was carried out at Crossness by the Native Guano Company, but led to nothing.

Even now proposals are still put forward for utilising the London sewage. One suggestion was that of an inventor, gifted perhaps with less knowledge but more imagination than his fellows, who proposed to supply the United Kingdom with alcohol from London sewage. Many curious proposals for making use of London sewage have been put forward from time to time by the large army of inventors, but no proposal has ever got beyond the pre-

liminary stage. Several enthusiasts on the subject of the useful utilisation of London sewage have begged for sample gallons of it at the outfalls, and one even took away a barrelful, but nothing has ever been heard again from any of them, and the amount of sewage which they have taken away has made no appreciable diminution in the 322,000,000 gallons a day, which are still at the disposal of anyone who will take it in whole or part. Up to now the valuable matter, whether alcohol or other material, in large quantities of domestic sewage, where no trade effluents are taken in to any large extent, is very similar to the gold which exists in all sea water, but which, unfortunately, costs more to extract than it is worth.

At the present time, owing to the diminution in the number of horses in large towns, it is becoming increasingly difficult to get manure for market gardens; and as this difficulty becomes accentuated, the time may arrive when it will be worth while to consider the manufacture of fertilising material from the London sewage.

A few figures, in conclusion, to show the extent of these operations of the London County Council. The total discharging capacity of the outfalls and storm water pumping stations on both sides of the river for 24 hours is 2,121,000,000 gallons. The net capital expenditure on the main drainage works by the Metropolitan Board of Works was £6,824,377, while since the Council came into office in 1889 up to the 31st March, 1913, there has been a further expenditure of £5,369,477, or the enormous total of £12,194,354, or nearly one-half of a year's cost of the maintenance of the British army. The following table shows the quantities of crude sewage treated, the chemicals used in precipitating the

sludge sent out to sea, and the quantities of refuse intercepted at the gratings at each of the outfall works at Barking and Crossness during the year 1911–12:

	Barking	*Crossness*	
	Galls.	*Galls.*	*Total galls.*
Sewage treated..	65,558,363,000	52,482,313,000	118,040,676,000
Daily average ..	179,121,210	143,394,298	322,515,508
	Tons	*Tons*	*Tons*
Lime used ..	12,509	10,878	23,387
Proto-sulphate of iron used ..	2,777	2,556	5,333
Sludge produced and sent to sea	1,711,500	885,500	2,597,000
Weekly average	32,913	17,029	49,942
Refuse intercept'd at screens ..	3,471	2,878	6,349
Number of trips made by the steamers ..	1,712	885	2,597

A good and abundant water supply and an efficient system of drainage are the first essentials for the prosperity of a city, and third in importance to these in such a climate as ours comes a satisfactory provision of light and heat. As an illustration of what London does in this connection, I want to take the Charing Cross, West End and City Electricity Supply Company, for it has to carry on its work under peculiar conditions of difficulty. Just consider the demands made upon it. In the daytime, when the City offices are working at full pressure, lighting and heating appliances are making insistent demands for a full and steady supply of electric current; but by six, the offices with rare exceptions are closed down, lights are extinguished, and heaters turned off, and the City, from

the point of view of the Electrical Supply Company, as from the point of view of the policeman on his beat, becomes almost a city of the dead. But what of the West End consumer? Just when the needs of the City begin to fall off, the West End begins to make its fullest demand for light and power. The wants of the men returning from work have to be met; the sky-signs come out in a blaze of incessantly changing colour; the theatres and the restaurants add in no slight degree to the drain of power from the supply company; and, lastly, when the rest of the world is comfortably abed, the machine rooms of the newspapers close their heavy switches, and a great gush of current has to surge across the wires to give life to that most marvellous of mechanisms, the printing machine. No man, I think, can stand by a printing machine as a paper is going to press without paying his silent tribute to the wonderful adaptability of electric power as he sees it in the printing machine. They are getting ready for printing. Most of the cylinders are securely locked on the machine, and the engineer wants one of the wheels to make a quarter turn. Just suppose a carter with a team of sixteen carthorses trying to get them to move a heavy load just a quarter of the turn of the wheel. He would need to use clumsy scotches and brakes, and have his team in a ferment of indignation. In the machine-room, however, the engineer calls on the power station for just the amount of energy he requires, and he gets it delivered him on the instant. And later, when all is set and ready, and the machines start with a roar, devouring their nightly meal of paper, pouring it out in a foaming cataract of completed journals, think how the current must stream across the wires to

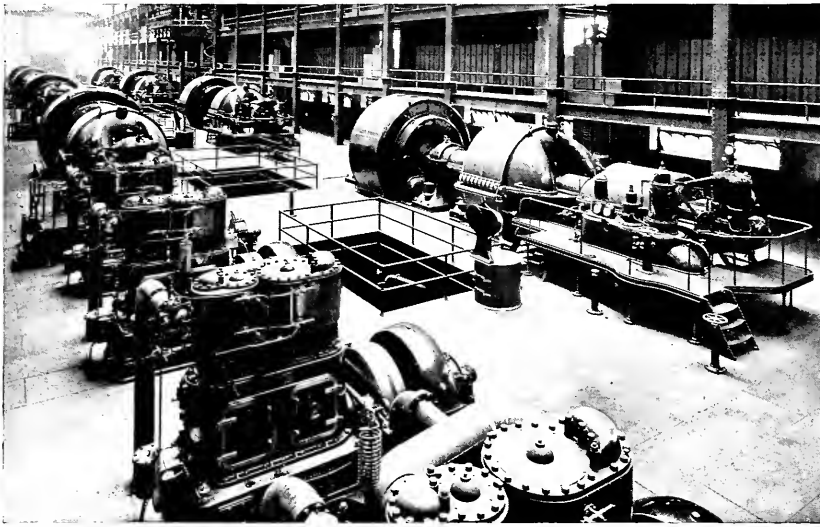


Photo: E. Milner, Wandsworth

THE TURBINE ROOM

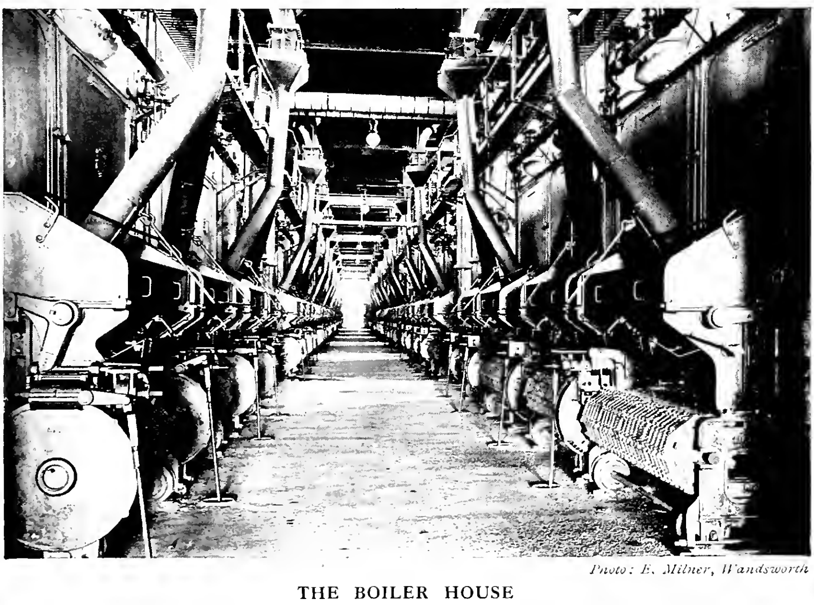


Photo: E. Milner, Wandsworth

THE BOILER HOUSE

A GENERATING STATION OF THE LONDON ELECTRIC RAILWAY

keep up the supply of furious energy that the work demands.

It is these and half a hundred other miscellaneous needs that the electrical supply companies of London find themselves obliged to cater for. Let us go down to Bow, the head-quarters of the Company, where they take the coal and absorb what they can of its energy so as to supply it in the handiest of all possible forms to the consumer. The huge chimneys of the building are the first things that strike the imagination; and they need to be big, too, to cope with the gases of the great furnaces beneath. In the building below there are three mighty boilers. Their fire grates have each an area of 336 square feet, and the heating surface of each reaches the enormous area of 22,000 square feet. It is no use stoking all these monster engines by hand. It would be rather like having the armies of Liliput hard at work pouring food and drink into the throat of a Gulliver; and so it is by their own mechanism that two of them draw in the coal that they require. The work they do is proportional to their appetite. It would be an easy matter for each of these giants to evaporate 100,000 lbs. of water in an hour. And beside these are a whole school of other boilers of lesser capacity steadily transferring the energy of the coal into steam pressure that the steam may change it to electricity. And the coal is brought them, broken exactly to their needs, both by rail and by water.

You get a wonderful impression of power by looking at the vast engine-room. The steam comes up to it in monster pipes, each of the pipes delivering its supply at a pressure of 170 lbs. to the square inch, and the engines

maintaining a steady vacuum of 26 inches in their condensers. They have special cooling towers to take the heat from the condensing water, and the fall in temperature from the top of these towers to the base is kept at a steady difference of 32° F. Coupled to the ever-turning, ever-humming flywheels of these mighty engines are the huge current generators. In looking at them you get the same feeling of relentless, insuperable power that you get in looking at the turbines of a mammoth liner. You see a little blue flame as the brushes spark, you hear a steady hum, and you know that in the world outside men are dependent on these wheels being kept incessantly turning for their bread-getting and for their amusements. With the old marine engines you could have a feeling of sympathy. It did not need much imagination to see them corresponding with a team of struggling horses, but with the turbine and the dynamo we feel in a mysterious way that we are watching the super-machine—a machine that has thrown aside all kinship with the animal world.

CHAPTER IX

CONCRETE CONSTRUCTION—A VISIT TO THE NEW STATIONERY STORES—A SKYSCRAPER—THE NATURE AND USES OF CONCRETE

For several months past now there has been a building in London in the course of construction that has excited the public interest. For my own part, I remember one afternoon some months ago, as I was walking along the Thames Embankment with an architect, that he drew my attention to it, pointing out to me that it was of particular interest because it was being built in the way they build a ship. We looked across the river, and all that we could see of the work was the lofty steelwork of the gantry cranes, appearing in the distant sunlight like those imaginative pictures of machinery that are drawn to illustrate the books of Jules Verne and Mr. H. G. Wells. When the time came for me to have to write a chapter on the methods of using reinforced concrete I thought of this building, which is to be the new Stationery Office and Office of Works Stores, and which is being put up on the Hennebique system of reinforced concrete. The Office of Works having kindly given me permission to go over it, I went there early one Saturday morning, and in an hour's tour of the unfinished building I learnt more about concrete construction than I could have done by hours of reading.

How London owes its very existence to the Thames!

Here is a building covering an area of some eighty-five square feet, destined eventually to have seven floors, and almost the whole of the vast weight of building material has been brought up to it by the Thames. Further, the building itself has been built almost completely out of material that has at one time formed the bed of the river. You can't help thinking of this as you stand by one of the big concrete mixers.

It is a great drum-shaped metal vessel, driven round rapidly on its axis by electricity, and lying in piles beside it are the materials on which it feeds. There is what the Clerk of the Works describes as ballast, gravel that has been scooped from the river-bed and washed perfectly clean; then there is the gritty sand, also washed perfectly clean; and, lastly, the cement, dug from the Thames Valley near Gravesend, burnt in the great mills there that form no small factor in giving us the London fog, and brought up to just opposite the building in barges by the tides of the river. The mixer takes 4 feet of ballast, all of which has passed through a sieve with a $\frac{3}{4}$-inch mesh, 2 feet of sand, and 1 cwt. of cement, and water, and it churns the mixture together into a paste, and then disgorges the lot into a great bucket that is carried by the cranes to just where the workmen require it.

When I went over the building the basement had been completed for months. The building stands on a forest of pillars, and in the basement they are at their thickest. The columns there are 22 inches square, and as they run up to the top story of the building they get thinner and thinner, being at the end only 10 inches square. It was while I was looking at these pillars that

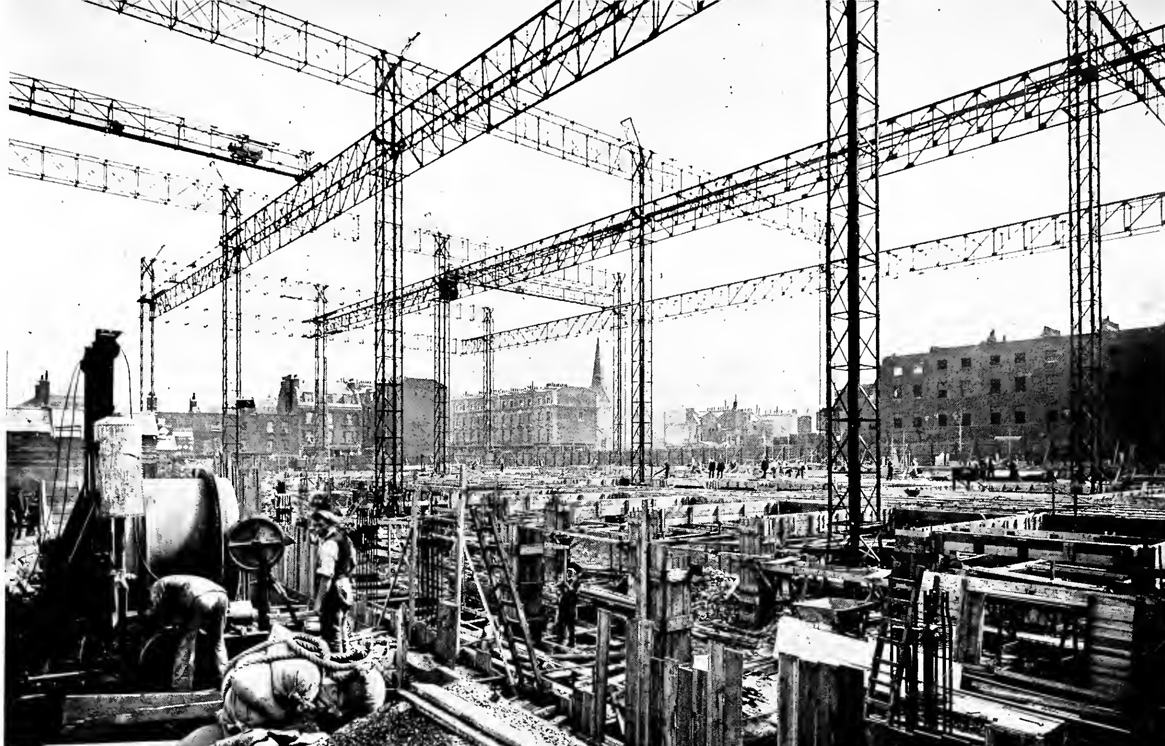


Photo : Ernest Milner, Wandsworth, S.W.

A NEW METHOD OF BUILDING

The huge steel gantry used in constructing the new H.M. Stationery Office

the Clerk of the Works gave me a few figures as to the forces that this concrete building has to support. "The floor above us," he said to me, "is just 3½ inches thick, and it has to be ready to support a weight of 3 cwt. to the square foot. The whole weight of the building, not only that of the floor above, has to be carried by these pillars, and as the foundations must not bear more than a load of 3 tons to the square foot, the pillars rest on large octagonal plates of concrete built on the solid foundation beneath our feet. You will notice," he went on, as we looked up at the ceiling, "how the concrete has the appearance of wooden beams. We shall see the meaning of that better later on, but all this concrete, pillars and beams and flooring has to be built in wooden moulds, and when the concrete has had time to set the wooden supports are knocked away and the concrete is strong enough to support itself, and the load of the building above it."

Apart from the interest of such a building as this, it is worth while being up at the top of it early in the morning on a fine day, such as I was lucky enough to strike. From the top floor you can get the whole idea of the building and the way it is being put together. The first thing that holds the attention is the sight of the gantry cranes at work. It is like looking at the skeleton of a megatherium, and one can imagine a line of evolution where such monster beasts had decided to get rid of muscles and blood, and to build their bodies of bare bones. The cranes dominate the building. In a later chapter we shall see that they are, in fact, a developed form of the transporter bridge. Each crane really consists of a wide-gauge pair

of rails, but whereas the gauge of a railway is measured in feet, the gauge of the cranes must be measured in several tens of yards. On these rails which traverse the space above the building from end to end the traveller runs, going 462 feet a minute with a load of 30 cwt., taking the place of the engine and the train, and, lastly, slung so as to run to and fro along the traveller, corresponding to the direction of the axle trees of the carriages, is the crab—so called as it only moves sideways—through which the materials are both moved to and fro along the traveller and are also raised or lowered. The whole is directed by a man sitting in a little cabin below the traveller, with three levers, one for each of the operations the crane is called on to perform.

You will have learnt in geometry that the position of a point is determined by the intersection of two straight lines, and the man in charge of the gantry crane spends his life in the application of this principle. I think it is worth while for us to have this made clear in a diagram, as, though the working of the crane is easy enough to understand when you see it in use, it may not be so clear from a description. A B C D is the rectangular piece of ground over which the crane works.

The traveller is a great carriage the width of A C, and able to travel in the direction A B or C D, or vice versa, while the crab runs in the direction A to C, or B to D, or vice versa. Let us suppose the crab is at A, and the carriage lying along A C, and there is a bucket of cement on the ground at P which is wanted by the builders on the top floor at Q. What the crane man does is to run the carriage or traveller from A C to A′ C′, to drive the crab from A′ to P′,

and then to lower his chain from the crab and pick the bucket up so that it is clear of the building. The bucket is wanted at Q. Well, the traveller moves from A′ C′ to A″ C″, and then the crab from P′ to Q, where the bucket is lowered down to the builders who are waiting for it. As a matter of fact, the crane man, being an expert, will probably do both operations at once, and in consequence the actual paths of the bucket will be A P and P Q, instead of, as I have described them, A A′ P and P P′ Q. If you are a geometrician, you will see at once that the whole problem is one that can be stated in terms of perpendiculars to the sides of the rectangle. What is the advantage of the gantry crane over the ordinary one which the workmen describe as a Scotsman? The point is that a Scotsman can only work within the radius of his beam, whereas the gantry, which is built over the whole building, can bring his chain over any desired point, and so in a building of reinforced concrete the workmen do not have to carry heavy loads across the cement while it is still "green," that is, while it is only lightly set.

We can see from the top every sort of operation being carried on at once. Here is a man bending the iron bars necessary for the reinforcement of the concrete, an easy enough job when you see it done, but needing its own special skill for it to be done with accuracy. A hundred yards away you can hear the circular saw buzzing its way through the wood, as it cuts it to the sizes the workmen require; and now we are at a floor that the men are just laying. These are the iron rods, necessary, as you will see when we consider the principles of the work, to supplement the concrete where it is weakest, and taking up the stress

of tension, and being quite light where the concrete is strongest in resisting compression. On this the workmen are spreading the concrete that has just been brought them in a bucket, putting their backs against the bucket to shove it just over the spot on which they want the concrete delivered, and then levelling the mass with monster squeegees. These steel rods have had more thought expended on them than you might imagine from looking at them. There will be 6,000 or 7,000 miles of them in the building when it is finished. Each has got to be able to resist a tensile strain of 27 tons to the square inch, but it must be so tempered that it would give way if the pull increased to over 32 tons, for experience has shown that as the steel gets above this strength, it only gains strength at the expense of being brittle. Then, too, each bar must be able to bend in its own diameter without fracturing. One bar at least from each consignment is tested at a proper testing works before the material is approved by the architect for use in the building. Close to the floor that we saw being built the workmen are getting a portion of the wall in place. At present it looks more like a trough than a wall, and as we look into the trough into which the concrete is being poured and rammed home, we notice again the iron rods for the reinforcement, but this time we see that they are specially tied together, partly so as to give resistance in a direction other than their length and partly to ensure that the building shall have what engineers describe as a monolithic character. It is only necessary to cross over what will be an office room, and we are beside a pillar that is running up to form a support for the floor

that is to be above where we are standing. The pillar has already three sides outlined in wood, but the farther side is as yet left open. Special care, we notice, has been taken to see that the four rods that run up the pillar are kept apart as far as their ties will allow them to go, for it is necessary that everything should be tight, as otherwise the concrete would have to bear the strain that the steel has been specially put in to support. At present the upper ties can slip up and down the steel rods, but in the part where the concrete has begun to be placed they are all kept tight, a bar of wood at first taking the strain, and being removed when the concrete has been rammed into position.

The new Stationery Office and Stores will stretch across a private street, and the two parts of the building are to be joined together by a bridge of concrete that will itself have three stories. The street would have been built over, but the adjoining hospital has a right-of-way, and the bridge is to span it at such a height as to place no obstacle in the path even of a fire escape that may have to come along.

We will pass over the staircases with just a mention, noting that they, too, are made of concrete, all so reinforced as to bear their own particular strain, and on our way out will glance at one of the floors that has successfully passed its test. For the purposes of the test, the floor was piled up with sacks of cement (each sack weighs 204 lbs.), and these were placed over the floor in layers nine sacks deep. The conditions of the test are that the floor of the building must not bend as much as the 600th of the span, and further, that when the weight is removed the floor must

come back accurately into position. In the present case the floor only gave a fifth of the amount allowed, so that the test was a triumphant success.

The new office and warehouse is to be a notable building, and the decision to have it built of reinforced concrete will have a great effect in stimulating the use of the material in England. Here are a few figures, showing some of the dimensions :—

Frontage	323 feet, 189 feet, 377 feet and 106 feet
Average height	77 feet
Height from floor to floor ..	11 feet in office ; 10 feet 6 inches in warehouse (generally)
Lifts	Ten for goods, two for passengers, and one for stores

Floor loads allowed :

In Warehouse, Ground floor	3 cwt. per square foot
,, ,, other floors	$2\frac{1}{2}$ cwt. ,, ,,
In Offices, all floors ..	100 lb. ,, ,,
In Offices, roofs	65 lb. ,, ,,
Floor thickness	$3\frac{1}{2}$ inches
Boiler chimney	110 feet high

In building, generally, I suppose there is no type much more wonderful than the New York skyscraper. It has been evolved, like all types of construction, even the old lake dwellings of Bœotia, from the special needs of the environment. New York is peculiarly situated. The area of the city is strictly limited, rents are very high, and there is incessant competition for office-room owing to the volume of business that continually passes through the city. Consequently, as it is physically impossible for the

Photo: Topical Press

THRILLING MOMENT IN THE BUILDING OF A SKYSCRAPER, NEW YORK

city to extend laterally, it has had to mount skywards, and in the Woolworth building the enormous height of fifty stories is to be reached. In most cases, to save the cost of rent, it is necessary that the contractor should have the old building down and the new one ready for occupation within a single term. In the circumstances it is easy to imagine the strain that is placed upon the engineer responsible for the erection of this class of building. It is the old story of complete organisation being essential for the satisfactory carrying out of this work. Once the ground has been cleared, and the foundation laid, the new materials, all properly numbered, must pour in in an incessant, orderly stream, so that the workmen will not be kept idle a moment, but will merely have to fit together the new building as fast as they can fix and bolt its constituent parts into place.

As yet, curiously enough, reinforced concrete has not entered largely into this class of building, though it is used extensively for the foundations; and it is because of the speed of the work and its extensive character that it is chiefly remarkable. The building is all constructed on a skeleton of steel, and the first point that strikes the onlooker is that it is the usual custom for the engineers responsible to start putting in the walls from the middle, and then building them upwards and downwards. The next point is the marvellous coolness of which the workmen engaged are masters. It is nothing for a man standing on a 6-inch beam with a gale blowing to catch a red-hot rivet that is thrown to him, or to wait with the slightest of foothold to have a heavy beam that has to be fixed in place passed to him. At night, the whole structure is a night-

mare of steel girders with the flare lamps, enabling the relay gangs to continue constantly at work. The depths to which the engineers have to go for foundations is at times enormous. In the case of the Manhattan building, which is a good instance of the general type, they had to dig 120 feet down to reach a solid foundation, which is not such a surprising figure after all, when you remember that the complete building itself weighs something like 100,000 tons, with another 20,000 to be allowed for wind pressure.

An interesting feature about the skyscraper is that the pressure it puts on its foundation is, after all, not so enormous. The City regulations refuse to allow a greater average load than 15 tons to the square foot. Now this works out to a matter of about 230 lbs. to the square inch, so that you get the paradoxical fact that if a 17-stone man stands with one foot on a nut that is an inch square he is bringing a greater pressure to bear on the ground beneath the nut than a skyscraper is bringing per square inch on to its foundations in New York. An estimate has been made to find out just what height of building could be reached without violating the building regulations on this point of pressure on the foundations, and it has been agreed that on a site 200 feet square a building might be erected 150 stories high, reaching 2,000 feet in the air, and weighing over 500,000 tons.

In connection with these skyscrapers, it is interesting to note that an instrument has been devised to test how far there is any dangerous movement in the concrete beams. It is a measuring instrument, and the operator bores two minute holes and measures the distance they are apart

under different conditions with extreme accuracy, being able to draw the valuable conclusion as to how far the building is in any need of repair owing to the girders not taking the strains that they have been intended to bear. The instrument has been aptly spoken of as the clinical thermometer of the building, and so extremely sensitive is it that it has been found possible from the observations made with it to determine on which floor of a building a gang of workmen were assembled.

Having started this chapter with the account of the new Government building, and having indicated the causes that have led to the skyscraper, we must turn back now to hear something of the nature and history of this ferro-concrete or reinforced concrete. As with road construction, and as with the building of the Eddystone Lighthouse, so with reinforced concrete, the object of the inventors has been to get a monolithic substance; something, that is to say, that will distribute any strain that falls on a part of it throughout the whole. Now, in 1898, when Mr. Mouchel first undertook the design of Hennebique ferro-concrete, there was not a single example of genuine ferro-concrete construction in the United Kingdom, but in the short time that has elapsed since then over 1,300 structures have been completed here, while if one took into account the buildings of the sort all over the world, the total would reach well over 25,000.

On what do the peculiar merits of ferro-concrete depend? I write peculiar merits advisedly, because by the time you have reached the end of this chapter you will agree, I think, that a substance that can be put to all these diverse uses must have many peculiar properties to recommend it.

Steel and cement have vastly different properties, and the essence of ferro-concrete work is that metal strips are embedded in the liquid cement at just those places where it is known that the heaviest strains have to be met. By a peculiar piece of good fortune, from the builder's point of view, it has been found that the whole material is firmly welded together, the cement and steel becoming tightly united by physical and chemical action. Cement or concrete is able to withstand enormous pressure, and it can be relied on to bear the vast weight of 600 lbs. to the square inch. Six hundred lbs. to the square inch, you think, is nothing so enormous, but conceive of it as 600×144 lbs.—that is nearly 40 tons to the square foot—and this will give you a greater respect for the resisting properties of the cement. It is far less strong, however, if you try to pull it apart, and what engineers describe as its stress in tension is limited to somewhere in the neighbourhood of 60 lbs. to the square inch. Let us think now of a beam made of pure concrete with a weight pressing on it. The beam obviously tends to bend—think of a man pushing a wheelbarrow over a wooden plank—and when such a beam is attempting to bend you have only to consider the problem to realise that the under portion of the beam is tending to stretch—that is to say, is being subjected to a tension stress—while the upper part of the beam is tending to be compressed. To prevent the solid concrete beam from breaking, therefore, it must be made so stout that the stress in tension does not exceed a pull of 60 lbs. to the square inch, and you can't do this without at the same time having the upper part of your beam so thick that the compression stress, too, does not

exceed 60 lbs. to the square inch. But we have already seen that the beam could safely bear a compression stress of 600 lbs. to the square inch, so we are faced with the unsatisfactory conclusion that nine-tenths of our material $\left.\frac{600-60}{600}=\frac{9}{10}\right\}$ is being utterly wasted.

It is right here, as our American friends would say, that the ferro-concrete engineer comes in. In the lower portion of the beam he embeds a couple of steel bars, and the steel being far stronger than the concrete, especially in resisting tension, our concrete bar gets support just where it needs it most, and the result of the whole thing is that a ferro-concrete beam is produced that will do the work of a steel beam at a saving in cost of between 15 and 20 per cent.

Engineering, you may think from a statement like this, might almost be described as the art founded on the proverb that a penny saved is a penny earned. We should not be looking at the matter in that case in quite correct perspective, but we should have thereby grasped a very important aspect of the subject. Given engineering skill, and given that an operation is feasible, the problem before the engineer is always one of pounds, shillings and pence. He must continually ask himself what is the cheapest way in which a given work can be accomplished. This does not mean that he must put in bad material or scamped work, for this is the falsest economy, resulting possibly in loss of life and certainly in a larger increase in the ultimate cost.

I have given the simplest example I could think of to illustrate the principle of ferro-concrete work, and if

you look at a treatise on the subject you will see that the reinforcement, as the addition of steel is called, has to be carried out on the most thorough and careful lines, the steel used being arranged and shaped in all sorts of curious ways so as to meet the stress to which it is subjected.

One of the amazing things about ferro-concrete is its durability. When Mr. de Vesian lectured on the subject recently, he was able from his own experience to use these remarkable words :

"Every engineer and every architect knows that lime concrete employed by the ancient Romans has endured to our own times, and that iron embedded in the same variety of concrete has been preserved for thousands of years without a trace of corrosion. With ordinary construction the fact has to be faced that the strength of the works must depreciate year by year, in spite of costly maintenance charges, which become more serious as time rolls on. Quite different is the position with ferro-concrete construction, the strength of which materially increases during the first few months, and goes on increasing for all time, although, of course, at a steadily diminishing rate. Hence, for ferro-concrete, the first cost is the last and only cost."

Mr. de Vesian was able to give a striking illustration of this in connection with the recently constructed General Post Office building. Four-inch cubes were taken direct from the machine in which the material was being mixed and laid on one side. A test on one of these after two months showed that 1,800 lbs. weight had to be applied to crush one of the cubes. At six months 3,500 lbs. were needed

to crush a cube, and at eighteen months 4,200 lbs. The ferro-concrete engineers have not rested content with studying the remains of iron in Roman cement, but have made tests of their own on this point with modern material. Many striking examples of these tests could be quoted, but the most curious and searching one that I know of was in connection with some piles that were being used at Southampton. When the time came to put them in position, it was found that they were too long, and lengths were cut off them, and the ends thrown upon the foreshore, where they were covered and uncovered by the tides four times a day. Now, obviously, the ends of the iron bars were exposed, and when several years later the bits of the piles were examined, it was found that where the iron lay even so little as a quarter of an inch under the protection of the concrete, it was as bright and free from rust as the day on which it was put in, whereas wherever it had extended beyond the concrete it was almost entirely eaten away.

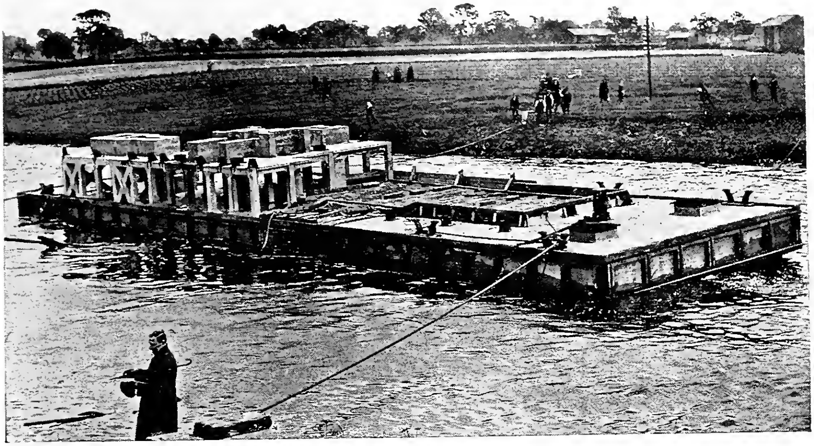
I wrote a few pages back of the monolithic character of ferro-concrete. This applies not only to an isolated block of the material, but to the structure as a whole, if it has been properly designed. Accidents have amply proved this point for the engineers. There was a case, for instance, at a tramway depot where one of the cars ran off the lines and collided with and broke the supporting column dividing the shed into two spans. The column was completely shattered, but the building as a whole resisted the shock, the rest of it at once taking up the strain that was intended to be borne by the central column.

On another occasion, too, a truck ran into one of ten

ferro-concrete legs that were supporting a set of coal bunkers loaded with 1,200 tons of coal. As before, the individual column broke, but no damage was done to the structure as a whole.

I suppose the accompanying illustration, however, gives the most remarkable instance of this that has occurred. Messrs. L. G. Mouchel and Partners were at work constructing a bridge over the River Tiber at Rome. The bridge in question is 328 feet long, and is the largest single span ferro-concrete bridge in the world, and was built in connection with the Rome Exhibition of 1911. Temporary piles had been driven into the river-bed to form a support while the work was being set up. One night, before the cement had properly hardened, a vessel came blundering along and collided with the staying, knocking away one of the principal supports. There would have been every excuse if the bridge had given way, but even though the concrete was not properly set it resisted the shock, and took up the very unfair strain to which it was subjected.

You would hardly expect concrete to withstand vibration, but its properties in this connection are so amazing that it is regularly used for making piles, and is the one safe substance for building houses in earthquake zones. You must certainly have seen piles being driven home and will remember how it is done. The pile is loosely fixed, and then a machine above it raises a weight of several tons to a height of some feet, and drops it on the pile. You can hardly imagine anything more likely to shatter a substance, but the piles resist the shock perfectly.



A PONTOON MADE OF CONCRETE

Photo supplied by Messrs. G. L. Mouchel & Partners, Ltd., Victoria Street, Westminster, S.W.

CONCRETE BRIDGE AT ROME: THE BROKEN SCAFFOLDING

Photo supplied by Messrs. G. L. Mouchel & Partners, Ltd., Victoria Street, Westminster, S.W.

Ferro-concrete is so much a building material of the future that, in conclusion, I will refer to a few of the strange uses to which it has been put. The idea of a vessel in stone —and it is hard not to regard concrete as a kind of stone —is almost as unthinkable to most of us to-day as an iron ship was to our forefathers. But recently a sludge pumping pontoon has been built for use on the Manchester Ship Canal. This astonishing vessel is 100 feet long, 28 feet wide, and 13 feet deep, while it draws 5 feet 6 inches of water when fully loaded. The hull, even under the boiler, which weighs 58 tons, is only 4 inches thick, and 3 inches thick elsewhere. The interior framing is made of ferro-concrete columns and struts. The vessel, you will realise, has to withstand all sorts of shocks, for the mechanical plant on the upper deck consists of a compound vertical steam-engine, condenser, three centrifugal pumps, and three steam winches, while even the bollards (the posts in the deck) by which the vessel can be moored or towed are made of ferro-concrete.

The uses to which Portland cement, which after all is the basis of ferro-concrete, can be put are so many and varied that they can best be dealt with in tabular form. For my material I am indebted to the courtesy of the Associated Portland Cement Manufacturers, Limited. The following are among the uses to which they ascribe its having been put in the handbook they publish on the subject. As you will see, the variety is extraordinary.

Foundations	Swimming baths
Walls	Fence posts
Piers	Garden steps

Posts
Floors
Roofs
Steps
Stairs
Paths
Pavements
Roads
Joints in drains
Manholes
Cesspools
Pipes
Mains
Conduits
Sewers
Culverts
Houses
Belfries
Theatres
Motor pits
Churches
Lavatories
Fives courts
Racquet courts
Strong rooms
Barns
Apple stores
Cattle sheds
Piggeries
Chicken houses
Drinking troughs
Dog kennels
Dairies
Garden rollers
Sundials
Water towers
Greenhouses
Cow stalls
Mangers
Tanks
Laundries
Mushroom cellars
Cisterns
Well kerbs
Reservoirs
Clothes poles
Terraces
Rockeries
Pergolas
Vases
Tree fillings
Jetties
Dams
Docks
Caissons
Groynes
Railway appliances
Signal boxes
Telegraph posts
Masts
Ships
Barges
Furniture
Tombstones
Balustrades
Bridges

Root cellars
Silos
Gas tanks
Seawalls
Sleepers
Rifle ranges
Pontoons
Vaults
Harbours
Canals
Lighthouses
Stations
Electric standards
Boats
Blackboards

CHAPTER X

BREAKING VIRGIN SOIL—AGRICULTURAL MACHINERY AND ITS USES

The problems of the farmer, you may be apt to consider, have no place in a book that professes to be all about engineering, but this is largely because most of you, at any rate, who see this book will understand by agriculture only the processes that go on in civilised soils, that is to say, in made ground when the roughest operations and the works carried on, even on the largest scale, are to the operations necessary to bring land into cultivation just about what ordinary suburban gardening is to the heaviest of farm ploughing.

It is amazing, when you come to think of it, how the farmer is able to change the whole face of a country, but still more astonishing to know that Nature has her own agencies constantly at work changing and altering everything. The story of wind and water and sand and earth movements changing the land, as we know it, is a fascinating chapter in geology, but this is not the place to describe them. I can only here refer to one of the humblest of Nature's engineers, the earthworm. The great naturalist Charles Darwin has told the story of a field that his boys used always to speak of as "the stony field," because the stones were so thick there that they clattered as the boys ran down it. The field was left to itself for 30 years, and

its aspect then had so changed that a horse could gallop uphill without his hoofs touching a single stone. All this change had been brought about through the agency of worms, which are continually passing the subsoil through their bodies, and bringing it up to the surface in the form of worm casts. The discovery is one of the many that have to be placed to the credit of Charles Darwin.

It is when you pass from the hedgerows and beautifully trimmed fields of England, and get right out to virgin land, that the engineer really begins to enter into the domain of agriculture. Let us imagine ourselves out in wild forest country, and let us suppose that the settlers have cut down the trees, using one of the powerful motor saws to do it, or having recourse to the old backwoodsman's axes. The land is all scarred with the traces of the workers, but the ground is, as yet, untamed. No ploughman could thread his way through the maze of stumps that encumber the ground; no plough, however powerful, could tear through the massive roots. In the past, man has had recourse to all sorts of devices to get rid of such obstacles as these. He has shattered them with explosives, burned them out of the ground, and tried all sorts of devices, only to find that the cost is too great to justify the work. And it is now that the engineer with the big forces that are at his disposal comes to the rescue of the farmers. Messrs. J. and H. Maclaren, a firm known all over the world for their heavy agricultural machinery, have kindly sent me an account of the way the engineer sets to work, and the following achievement stands out as typical of the work he is called upon to do. The problem was to clear a great tract of the Tintinara Desert, in South Australia, and

the land was covered with whipstick, wattle and gum trees up to $2\frac{1}{2}$ feet in diameter. For the heavier work that had to be done a pair of 16 horse-power Maclaren ploughing engines, from which the gear had been removed, were pressed into service. The engines were placed parallel to each other about 2 chains apart, and facing in the same direction. One end of a wire rope about 450 feet long was fastened to each engine, and as the engines moved forward they cleared a track, pulling the trees up by the roots, and tearing off such branches as stood upright. It was claimed that the cost of this clearing did not exceed 6s. an acre. A tree with a diameter of $2\frac{1}{2}$ feet is a good-sized tree, but when you are dealing with virgin forest vastly bigger trees have to be dealt with, and special machinery has been devised to meet the case. Messrs. Maclaren have made a number of special engines for this particular kind of work. They are generally similar in appearance to traction engines, but they differ in certain important particulars. They are fitted with a special winding drum on the main axle, taking a steel rope of about $1\frac{1}{2}$ inches diameter; the gearing for this drum is very powerful, having a direct pull equivalent to a vertical lift of 15 tons. The method of working is very simple: the engine is taken into the paddock to be cleared, and anchored by the front end to a fixed claw anchor, one or more of the firmest stumps, or any other anchorage which may be convenient. It is still further secured by the brakes being screwed hard on, and the wheels scotched by large pieces of waste timber. The engine works in connection with two sets of men, called the "chain gang," whose duties consist of fixing strong chains round the large roots in preparation

for the steel rope which is to haul them out. The rope is paid out behind the engine, and hooked on to the chain, which has been fastened round the stump. The winding gear is then put in motion, and no matter how firm a hold the roots may have in the ground, they are quickly torn out. There is seldom a root that can resist the pull of this rope, and the operation is done so quickly that both sets of men are kept busy fixing the chains. The work progresses rapidly, because while the engine is hauling for one set of men, the others are preparing their stump, and so the engine is kept constantly at work. By the time one stump is drawn, another one should be ready for the pulling rope. Many acres of land can be cleared in this way in a very short time, and the stumps with their principal roots can be drawn into a suitable position, and there burned. After this operation, the land requires very little in the way of clearing, but if necessary this can be done quickly and cheaply by means of an instrument known as a "colonial knifer."

The extent to which elaborate machinery has entered into agricultural work is amazing. It is becoming more and more the practice for heavy haulage to be done by engines. Ploughing on a large scale is effected with heavy agricultural machines, and by the kindness of Messrs. John Fowler and Company I can show you how the farmer succeeds, even in the wildest districts, in forcing the stubborn land into cultivation. The ordinary method is to have two powerful engines placed 400 or 500 yards apart on the opposite sides of the field. You might almost take them for traction engines, but if you look at them you will see that they are furnished with an enormous drum.

Round this drum a steel cable is coiled. The cable is harnessed to a powerful steel plough, armed with several ploughshares, and the engines drag it alternately backwards and forwards across the land. Such an instrument as I have shown is intended for use when the land has been more or less cleared or when it has been brought under regular cultivation, but where land is to be broken extra strength is given to the plough. Land would have to be wonderfully strong to resist such an instrument as the heath plough, where the engine can get its full force to bear on a single share, or one of the five-tyre knifers that we can see at work clearing the land of roots and stones in the Hawaiian Islands.

Now, how is it these ploughs do their work in really difficult land? Take the case of some ground that was used for a test, in the middle of which there was a vein of bog iron ore running from east to west. In the one portion, with light, sandy soil, the plough could make its deep furrow without difficulty, but in the middle the steel shares began to creak and groan. The plough only moved forward by fits and starts. But the engine power conquered the elementary power of the ore veins. The stones broke with a crash, and were slowly but surely forced out to the upper edge of the furrow by the mould-board. Colossi of from 1,100 lbs. to 1,650 lbs. in weight were thrown up like mere sods. The trench of about 260 yards was made quite smoothly, and the whole work proceeded so noiselessly that the humming and puffing of the working engine could scarcely be heard.

Breaking heavy land is only one of the problems before the agricultural engineer. He has to drain marshes. One

of the classical instances of this type of work has been published by Messrs. John Fowler, who have printed it just as it was sent to them by the pioneer settler who did the work—Mr. J. R. Cox, who is a staunch believer in the use of heavy machinery for agricultural operations. The marsh in question lay a matter of 15 miles south-west of Algiers. It had an area of 750 acres, and was the source of all the malarial fever in the neighbourhood. Several canals had been cut in it, but these did not let the water that welled up from the springs escape, and the marsh was growing an increasing danger to a thickly-populated neighbourhood. I will let Mr. Cox tell the story for himself:

"It was impossible to cut the reeds and weeds, which attained a height of 5 feet, because it was exceedingly dangerous for men to venture on such a quagmire, where a number of oxen had already perished. Owing to these difficulties, it was not possible to see what work should be done for draining off the water. I therefore resolved to try with my Fowler's engines what results could be obtained. The plough being pulled by the rope of each engine, all that was necessary was to place the engines at a suitable distance from each other, and to make in front of each a road, which, while rendering the scheme practicable, would afterwards serve as a farm road. At first the ploughmen thought they would never be able to do the work. Twenty times during each bout the plough had to be pulled back so as to get it out of a hole. The land was turned over in bands about 10 yards in length, all in one solid piece, owing to the sticky nature of the soil and to the weeds. The large wheel of the plough was running in water; it was exceedingly trying for the ploughmen, and

the plough, time after time, had to be deviated from the straight course, so as to avoid a hole too big or too deep. Every furrow was full of water, but I was careful to make a ditch at each end. These ditches, whilst running along my engine roads and draining them, received at the same time the water from the furrows, which formed so many drains. The soil was thus drying naturally, and I was enabled to see the state of the ground, where the springs were, and also the low parts, so that I could make the necessary draining ditches. All the work was executed with Fowler's ploughing engines and one of their single-furrow deep-balance ploughs, the whole plant giving entire satisfaction. The first year oats were sown, and a splendid harvest was obtained in these lands, which hitherto had never produced anything. A great difficulty was experienced in advancing the engines forward. As I have previously stated, it was arranged that the passages for the engines would afterwards serve as roads; and with this in view, I filled up in front of the engines all the holes that were found with stones, pieces of wood, etc.—and when it was impossible to pass, or time was wanting for filling up a hole, the engine was made to travel a little farther out on one side, and the ploughing was made with a lengthening piece added to the rope. Of course, the work was not perfect. The weeds choked the plough, sometimes lifting it even out of the ground, whilst occasionally the plough disappeared in a hole, and we had to take it out with the greatest care, but every furrow made was a drain taking away so much water. Most offensive smells emanated from the land, and it was only due to the strong hygienic precautions enforced on the men that the latter escaped taking

the malaria. The harrowing was done the first year with a Fowler's steam harrow, but the implement suffered very much owing to the large lumps made by the plough when it had turned over that sticky, soaked ground. The second year the work was executed with more facility, for good roads existed, but it was still very hard work for the plough; a layer of land, about 8 inches to 10 inches deep, was completely dry, but the bottom part of the ground was still wet. That second year, the work having begun late in the season, the engines were blocked by the rains in the ploughed ground, and it was with the greatest difficulty that we were able to get them out. Last year (1902) the harvest has been made with a reaping and binding machine, which amazed the great number of visitors who had come to see it done, and who had known the marsh and shot wild duck on it; but another result obtained, and which, in my opinion, is the most important, is that fevers have been completely stamped out of the district."

Work like this, I think you will agree, is more closely related to engineering than to agriculture, but while we are still on the question of drainage, I want to describe to you two remarkably beautiful machines that are used for running drains through clayey soil to allow water to escape. The first of these is a trenching machine, which the sketch shows us from behind. In front, of course, there is a heavy knife or coulter, and when this has been drawn across the land the farmer has a well-made trench into which his land can drain. What of the side drains that are to lead into this? A special machine has been contrived to meet their case. The machine is started by lowering the

mole (the portion that burrows into the ground) into a specially dug excavation, and dragging it across the land. The drains thus made will keep open for several years.

Agricultural machinery is endless in its variety, and affords continual evidence of the ingenuity of the engineer. I learn from Messrs. Marshall, Sons and Co., of Gainsborough, that the application of oil as the source of energy for agricultural machinery has proved amazingly successful, and that they have been able to send their internal combustion engines all over the world. It is only natural that those who are going to use such engines should have wanted elaborate trials to satisfy themselves as to the reliability of the engines, and from a large series of photographs of their trials I have found proof of the perfect adaptability to their work that these engines possess.

Agriculture is one of the oldest of the arts, and it is a matter that sets one thinking deeply, when one considers the amazing alterations that the last 100 years have brought about. In the chapter on Water Power you will read how the engineer has laid hands on the very air to turn it into manure for the cultivators. In the machinery he now uses, the farmer is tapping all that expert skill that goes to the making of steel, to the designing of engines, and to the adaptation of scientific knowledge to the needs of everyday life. Why, further, even the laboratories themselves are being pressed into service, for no man now would dispute how important it is to the farmer that the experts should be able to advise him on biological problems, and as to the bacteriological and chemical condition of his soil. Agriculture, from being the special study of a separate class, has been drawn into that network of inter-related

arts and sciences of which engineering is one of the chief. That vast progress has already been made as a result of this collaboration is patent to every man who has the eyes to see, but there are, I think, none of us who can realise the stupendous developments that lie before us in the future.

CHAPTER XI

MINING—THE CONSTRUCTION OF A COAL MINE—DIGGING FOR GOLD—HOW OIL IS SECURED

ENGLISH history starts with the tin mines of Cornwall. In the early days, when the sea was full of the wild romance that Homer has crystallised once and for all for us in his wonderful narrative of the wanderings of Odysseus, the adventurous Phœnicians would pass between the Pillars of Heracles and cross the Bay of Biscay in their search after the products of the tin mines, bartering wares with the savage natives of the seashore. Our country has lived up to the early traditions of the native Celt, for it is as much or more on the firm basis of mineral wealth as of any innate Anglo-Saxon merit that her greatness is based. It is a point that in our pride of race we are apt to overlook, but the fact remains that English pre-eminence is in great degree due to her having had the good fortune to find iron and coal lying in close proximity, only needing to be brought together to be successfully worked. With this natural advantage England secured the lead in the manufacture of steel, and succeeded in making herself the factory of the world.

Mining lays every art and every craft under contribution, and volumes would be needed for anything like an adequate account of the methods used to be described. We shall probably get the best idea, however, of mining

if we try and see the ordinary way in which coal is got from the earth.

A colliery from the outside is an unsightly place. There are the twirling wheels at the pit-head, the vast stacks of coal waiting to be loaded and sent off, and the great rubbish heaps of inferior coal that has been brought up and dumped on the surface because it was found to be in the way of the miners at their work. But the mine has required a vast expenditure of thought and time and money before it has reached this stage.

The first event in the long chain of events leading up to the working of the colliery was when the men began to prospect in the belief that coal beds would be found lying below the surface. In such a case—and it may be regarded as the typical way in which coal-mining begins—the first thing is to bore a hole deep down into the earth and thereby secure a sample of the different layers.

We will assume that the ground is soft. In such a case pipes will be brought to the site selected for boring; one of them with a cutting edge will be driven by blows from a heavy wooden block into the ground, another placed on the top, and the process repeated until a length of piping as much as 300 feet, perhaps, has been driven into the depths below. Into this large cylinder another pipe of smaller bore will be fixed, and then by a strong pressure of water in the smaller pipe the contents of the large pipe can be washed up for inspection.

A more interesting and a more elaborate method has to be employed where the ground through which the bore hole has to pass is hard rock. In these cases the method is to have chisel-shaped bits on the end of heavy rods, and

to keep these incessantly rising and falling, while with each stroke the whole rod and the chisel turn through a few degrees, so that the cutting is all the time being brought to bear on a new surface. When this has gone on some time, an instrument called a "sludger" takes the place of the chisel, and by an arrangement of valves picks up the debris at the bottom of the hole.

We will suppose that the information we have got from the bore hole is satisfactory. The next thing to do will be to sink a shaft down to the stratum of coal that we have discovered. The first difficulty is how satisfactorily to get down to the solid substance—what the miners call the stone-head—and for this various methods have been devised. Sometimes timber is used to form a coating for the shaft. It may be sufficient to line it with masonry, but there are times when the side must be supported by iron drums. It is when this stage has been reached that the miner needs his whole arsenal of tools. He has his diamond-shod drill to help him, whirled round by compressed air, perhaps, or driven by electricity; he has drills that force a hole into the rock by pounding it with sharp-faced chisels, and the material he excavates is continually being drawn up out of the shaft by the heavy iron barrels or kibbles that are perpetually being passed down to him. He must have powerful pumps at hand, prepared to deal with any inflow of water, and explosives to shatter the rock into which he has drilled.

Let us suppose the shaft successfully sunk, and that the miners have reached a stratum of coal. There are two chief systems on which the mine can be worked, called respectively the "bord and pillar" and the "long-wall"

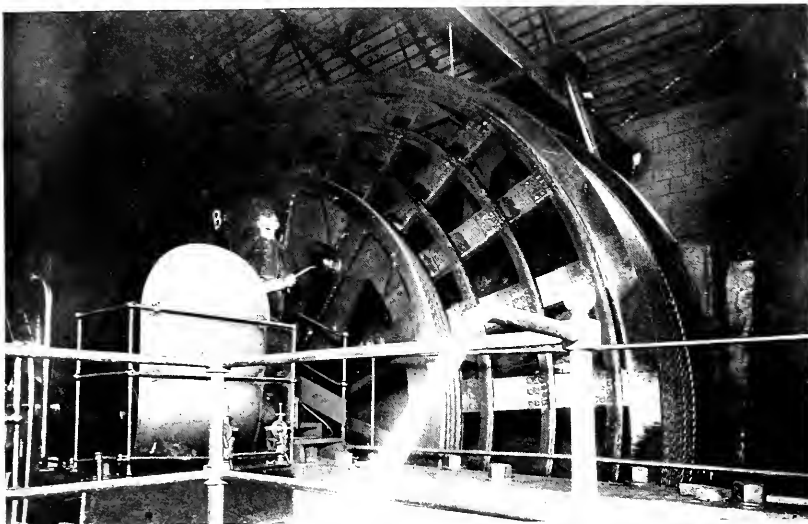


Photo: Topical Press

BIG WINDING DRUM WITH THE CABLE THAT RAISES THE CAGE

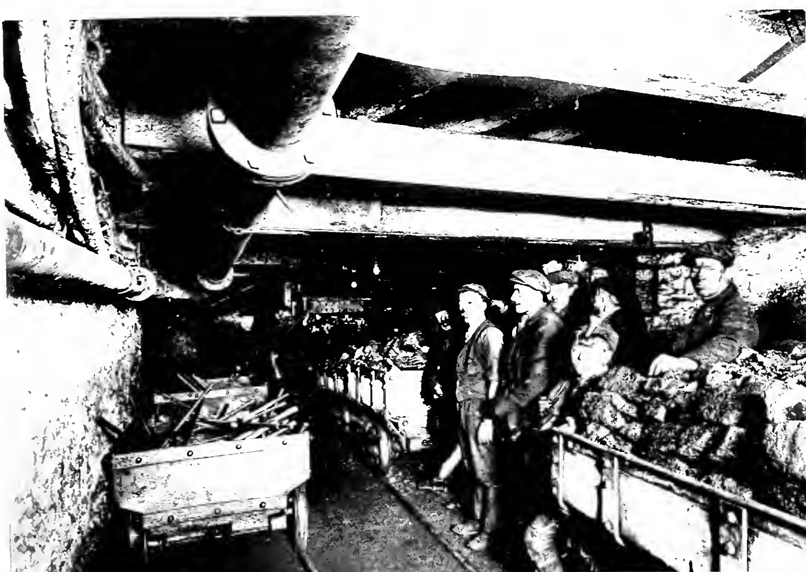


Photo: Topical Press

MEN WAITING AT THE FOOT OF THE SHAFT

COAL MINING

systems. Naturally, there are endless modifications of the two different systems, but as they form the basis of coal-mining, we may as well consider them in outline.

"Bord-and-pillar" working is the method pursued chiefly when the coal is present in deep seams. The essential idea of it is to drive galleries into the coal from a central road that has been first made, leaving portions of the coal behind to act as pillars. When the seam is eventually exhausted, the pillars are themselves cut away and taken to the surface. In the "long-wall" system, on the other hand, the practice is for the miner to undercut the seam of coal, shoring it up with props, and, when a sufficient amount of undercutting has been done, either let it fall by its own weight, or bring it down by the use of explosives.

There are few of us, I suppose, who have not been interested at one time or another in explosives, but the mining engineer has had to make a special study of them, and he has at his command a vast number of different substances each adapted for his special purpose. Gunpowder is the favourite explosive, for it gives out its energy in a slow heaving force, and brings down coal in large lumps, and it does not require the use of detonators to make it do its work. At times, however, a more powerful explosive is required, and this is got from some one or other modification of nitro-glycerine. Dynamite, for instance, is nitro-glycerine that has been absorbed in diatomaceous earth. Blasting gelatine, which is said to be the most powerful of all known explosives, contains 93 per cent. of nitro-glycerine and 7 per cent. of nitro-cotton. Gelatine dynamite, which has a heaving and rending rather than a shattering action, contains 80 per cent. of blasting gelatine,

the remaining 20 per cent. being made of nitrate of potash and wood pulp. Gelignite is similar in composition, and Rack-a-rock consists of a mixture of potassium chlorate and nitro-benzol.

When mines are dry and dusty there is, of course, the ever-present danger of a terrible explosion, and to guard against this, special forms of cartridge have been devised. There is the water cartridge, for instance, where the explosive, gelignite, is contained in a water-lined case, the water being designed to put out any flames at the moment of their formation; there is roburite again, consisting of nitro-benzol and ammonium nitrate, which on combination give rise to fumes that would quench any flame produced by the explosion, and ammonite, too, consisting of nitro-naphthalene and ammonium nitrate, and, indeed, a whole host of other special cartridges. The most beautiful of all, which, unfortunately, does not usually work very well from a practical standpoint, is the lime cartridge. In this perfectly dry lime is packed tightly in a cartridge, and the cartridge bedded home in the hole made by the drill. On the addition of water to the lime its volume increases enormously, exerting overwhelming pressure. Unfortunately, however, great difficulty is experienced in ensuring that the lime is perfectly dry, and if that is not the case, the cartridge is, of course, ineffective.

In addition to explosives, the miner has all sorts of ingenious machines to help him at his work. There are instruments, for instance, like circular saws, driven by compressed air and designed to undercut the coal. Others represent the bandsaw type, and others again, working by concussion, chip away the coal and save the miner a great

deal of time and muscle work. Electricity, too, has at times been employed with the happiest results, and if only all risk of sparking could be guarded against, it would have an enormously wide application.

One of the chief duties of the mining engineer is to ensure the perfect ventilation of his mine. The methods of doing this are, of course, manifold. In the old days, the idea was to have two shafts and keep a roaring coal fire blazing away at one of them. The fire heated the air and expanded it so that it rushed up the one shaft, while cold air came rushing down the other, and passed on through the mine to get heated in its turn, and make room for a fresh supply. Nowadays, the method is to have powerful fans driving in air, or sucking it out, an elaborate designing and stopping of the various galleries being necessary to ensure that the air circulates through all the different parts of the mine.

It is common knowledge that as you go down into the depths of the earth the heat becomes intense. The finest illustration that I know of the need for efficient ventilation comes not from the history of coal-mining, but from the account that Mr. Eliot Lord wrote, in the " Monograph of the United States Geological Survey," of the tunnelling work of Adolph Sutro, in connection with the Comstock silver lode. There was a period when the miners were some two miles from the nearest ventilating shaft, and the heat of their working chamber was fast growing too intense for human endurance. The pipe which supplied compressed air to the drills was opened at several points, and the blowers were worked to their utmost capacity. Still, the mercury rose from 98° F. on the 1st of March, 1878, to 109° on the

22nd of April, and the temperature of the rock face of the heading increased from 110° to 114° during the same period. From the first day of May, 1878, it was necessary to change the working force four times a day instead of three, as previously, and the men could only work during a small portion of the nominal hours of labour. Even the tough, wiry mules of the car train could hardly be driven up to the end of the tunnel, and sought for fresh air not less ardently than the men. Curses, blows and kicks could scarcely force them away from the blower tube openings, and more than once a rationally obstinate mule thrust his head into the end of the canvas air-pipe, and was literally torn away by main strength, as the miners, when other means failed, tied his tail to the bodies of two other mules in his train and forced them to haul back their companion, snorting viciously and slipping with stiff legs over the wet floor. It is a melancholy fact that though this work, with all its hardship, was successfully achieved, the promoter of it failed to reap the reward he had richly earned.

We must leave the coal mine, I am afraid, with nothing but a reference to such problems as the fixing of the gradients so that water shall drain to the pit shaft, and that the loaded trucks shall have down gradients, and be empty when they are dragged back, saying nothing of the elaborate experiments carried out to get to know what are the exact causes of explosions and how they may be prevented; of the difficulties in connection with the winding engines and their heavy steel cables; of the way in which dangers have been lessened by the introduction of the Davy safety lamp and other contrivances; and of the heroic way in which the miners carry out great works at lightning speed to save

their entombed comrades. There are many stories told of the extraordinary length of time that men have lived entombed, cut off from the world, without food. There was one case, for instance, where a miner was brought up alive after twenty-three days, and another where a man remained similarly alive for thirty. There is a Fleet Street story that illustrates this point of a journalist who was sent down to describe the grim struggle that the miners were making to release an imprisoned comrade. One day, finding the men were for giving up the task in despair, believing it hopeless that their comrade could still be alive, the journalist mendaciously declared that he had heard a knocking through the wall. Stimulated by this invention, the miners redoubled their efforts, and they were rewarded next day by hearing genuine knockings, and eventually rescuing the unhappy prisoner.

It is gold-mining, I suppose, that has made the strongest appeal to our imagination, and no wonder, either, when we read of the extraordinary effect that the mere rumour of gold being discovered exercises throughout the world. For an account of this extremely interesting side of the question, you must go to the works of Bret Harte, or to such books as Mr. Archibald Williams' "Romance of Mining." My task is rather to try and indicate to you the engineering aspect of the subject. Much of the work of the gold miner is done in shallow diggings, where his task consists in collecting the gold-bearing earth, or "dirt," and washing it by whirling it round and round with water in the pan. A little skill enables him to wash away the lighter portions of the dirt. Behind is left the gold in the form of dust and pebbles which there is no difficulty in removing by hand, the whole

process being known as "panning." A modification of this is to introduce mechanical rockers and to combine with them the use of mercury, which catches at any particles of gold, and forms an amalgam from which afterwards it can easily be liberated by heat. This process can hardly be described as engineering, but in some of the mines, water at high pressure assists the miners. Gold is found often embedded in gravel, and as it usually sinks to the bottom of the gravel, it is clear that it can only be mined either by driving tunnels through the base of the formation, or by getting rid of the mass of superincumbent gravel. The most effective way of disintegrating the gravel is by discharging, at the face of the formation, jets of water at high pressure. Meanwhile a tunnel will have been driven to a point below the gravel to a neighbouring ravine, and when the ravine bottom has been filled with tons of mercury the gravel will be driven along the tunnel by the force of the water, and the gold falling through the stream by the force of gravity will amalgamate with the mercury. It is clear that great engineering skill will at times have to be employed in order successfully to drive the tunnels to the places required. In his book on "Our New West," Mr. Samuel Bowles gave a striking picture of the devastating effect that this type of mining produces on the country-side. "Tornado," he wrote, "flood, earthquake, and volcano combined could hardly make greater havoc, spread wider ruin and wreck, than are to be seen everywhere in the track of the larger gold-washing operations. None of the interior streams of California, though naturally pure as crystal, escape the change to a thick yellow mud, from this cause, early from their progress in the hills. The Sacramento is worse than

the Missouri. Many of the streams are turned out of their original channels, either directly for mining purposes, or in consequence of the great masses of soil and gravel that come down from the gold-washings above. Thousands of acres of pine-land along their banks are ruined for ever by the deposits of this character. A farmer may have his whole estate turned into a barren waste by a flood of sand and gravel from some hydraulic mining up stream. More, if a pine orchard or garden stands in the way of the working of a rich gulch or bank, orchard or garden must go."

It is when gold is found interspersed with quartz, as in South Africa, and has to be mined, that the engineer proper has his greatest share in the work. In that country deep shafts have to be dug and the quartz definitely mined from the bowels of the earth. The crude material is brought up from below the surface in much the same way as I have described with coal, it is roughly sorted and broken, and then carried direct to the stamping mill where heavy metal stamps, weighing about a ton each, and worked by cams, break it to powder. Mercury is again used to pick out the gold, and then what is left, known as the tailings, is treated with cyanide of potassium which combines even more readily than mercury with the gold. When the chemical action is concluded the liquid is treated with zinc, which precipitates the gold in fine granules at the bottom of the liquid.

Diamond mining has, of course, its more special characteristics, and for very many years the origin and character of the diamond remained a mystery. So much so was this the case, that among the early inquiries sent out by the

newly formed Royal Society was the question whether it was true that where diamonds had been extracted from the beds in which they were found, the beds if left alone would produce fresh stones! At present, as every chemist knows, diamond is merely pure carbon that has been forced to assume its present crystalline form under high pressure and temperature. The most noted of the diamond fields are those at Kimberley, and the stones are found in the clay formation that occurs in the district in great "pipes," in some cases thousands of feet across, that have been squirted up from the bowels of the earth. The pipes are mined in very much the same way as is done with coal, and though the blue clay is very hard, it is found to crumble away after it has been exposed to changes of temperature and to water. After being strewn on the ground for a year, the material is sorted by the action of water, and the heavier portion of the "concentrates" is brought to the machine known as the pulsator, which throws it up and down and retains the diamonds owing to their having the property of being held in the grease at the bottom of the trays of which the pulsator consists. The last process is to melt up the grease, when diamonds and rubbish settle to the bottom and the diamonds can easily be separated out.

We have heard so much lately of oil fuel, and are certain to hear so much more of it in the near future, that we may as well learn something of the methods adopted by the engineer to drain the earth of this most valuable material. In its essence the work of oil boring is very similar to the methods that I have described as adopted by the prospector for coal, but in the old days—and even to-day, especially in Roumania—the favourite method was to dig pits as much

Photo: International Press Photo. Co.

AN OIL WELL SPOUTING

as 600 feet deep and allow the oil naturally to flow from the surrounding strata into these depressions.

Oil, as you probably know, is merely coal in another form, and with the changes that have taken place underground to turn the coal into oil, the usual experience is that a great deal of gas has been formed under high pressure at the same time, and when once the engineers have succeeded in tapping the oil-bearing strata, it may be that the well will flow for a long time, or indeed that there will be a violent discharge of oil and sand to the surface that for days, or even weeks, will carry everything before it. Such a spouting well has been aptly described as a gusher.

One of the hardest tasks that the oil engineer is asked to undertake is that of controlling these gushers once they have broken loose. Their action is so amazingly powerful, that with the sand they bring up they are able to pierce great sheets of steel. The method adopted has been so graphically described by Mr. A. Beeby Thompson, in his "Petroleum Mining and Oilfield Development," that I will quote you his description. He writes: "For many years it has been the practice in Baku and Grosny to place a massive steel or chilled cast-iron shield some 15 feet or 20 feet above the mouth of the well, the discharged mixture of oil, sand, and stones being thereby prevented from rising hundreds of feet into the air, and being dissipated by the winds. Heavy cross-timbers, to which the 12-inch blocks are bolted, are placed in the derrick when a flowing well is expected, and the timbers are so arranged that the block can be drawn over the mouth of the well by ropes from a distance when a flow commences or appears imminent. So destructive is the fiercely discharged mixture

of sand, oil, and gas, that the massive Russian derricks are often totally destroyed, and even the chilled iron blocks have been perforated one after another in succession by a particularly violent gusher. The unexpected appearance of a violent gusher generally leads to the loss of great quantities of oil through the absence of provision of a 'fountain shield,' the oil being ejected through the summit of the derrick to a height of 100 to 300 feet, with such impetuosity and with so much gas that the well cannot be closely approached. In such cases a side timber structure is often built to the derrick at a height of about 20 feet, and massive fountain shields are pushed over the mouth of the well from the side. The stream of oil is diverted along channels, kept open in the accumulation of ejected sand by gangs of labourers, to a depression where the pumps can deliver it to the storages."

All sorts of methods are used for extracting oil from deep-lying strata when the force of the imprisoned gas is not sufficient of its own accord to bring the oil to the surface. In some wells pumping is resorted to, in others bailers are used. A clever method is to aerate the gas so as to lighten the weight of the column, and thereby enable it to rise to the surface of the ground, and sometimes the oil is definitely forced to the surface by the pumping in of compressed air. A task requiring special judgment is the shattering of the oil strata by shots fired in the well itself. In favourable circumstances the flow of oil is very materially increased, but there have been occasions when the well has thereby been irretrievably ruined. Another particularly neat appliance brought into action is when a flowing well takes fire. If the flow is very powerful, it is no easy matter

to extinguish the fire, and the engineers have hit on the ingenious idea of injecting into the oil before it has reached the surface huge volumes of steam or carbon dioxide, or of some other non-inflammable gas, on several occasions with the happiest results.

The limits of the chapter might be extended indefinitely if I were to touch on the many romantic stories of silver and copper mining, or were to attempt to describe in detail the various methods by which men have to set about the mining of quicksilver, tin, iron, marble, granite, rubies, salt, sulphur, or the rest of the many substances that are dug from the bowels of the earth. If you have followed me so far, however, you will have realised a few of the difficulties with which the mining engineer has to contend. He must be a man of resource, for he will never know the hour when it may be his duty to devise a scheme to set free his men from imminent disaster; he must be gifted with an eye for country, an imagination that will enable him to guess at the direction that the strata are likely to take as they dip beneath the surface of the earth; he must have knowledge and judgment in an exceptional degree, for if his instinct misleads him, he may readily expend the capital available for the mine in valueless excavation, and, above all, he must be a man of sterling honesty, able to resist the temptation of so compiling a report on the prospects of the mine for which he is responsible as to please the directors of the concern in a greater degree than is just in the interests of the shareholders. With these qualities, and with the good fortune necessary in every walk of life, the miner has opportunities for which he will be envied by many of his fellows. He has work that brings him into

touch with his fellows when they are in the grips of the keenest emotion; he sees man both at his best and at his worst, and there will be times in his life at any rate when he will see or experience a fuller sense of the true meaning of romance than is given to the majority of us to enjoy.

CHAPTER XII

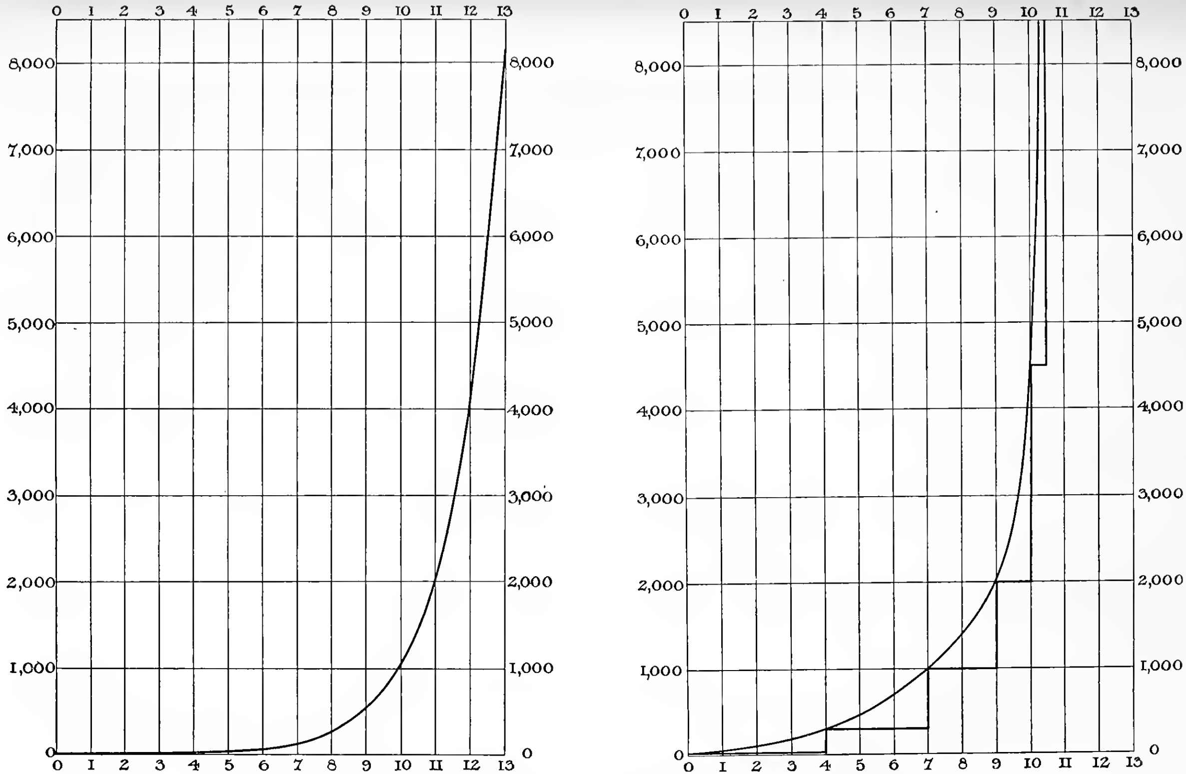
ELECTRICITY AND WATER—THE CONTROL OF NIAGARA—PUGET SOUND—FACILITIES IN SCOTLAND—THE ARTIFICIAL MANUFACTURE OF NITRATES

There has probably been no time in the history of the world when it has been so easy for us to look ahead. In matters of government there are many who hope much from the all-conquering march of Socialism, and many more who regard the idea as the waters at the bottom of the steep slope down which the demon-driven Gadarene swine were hurried to their doom. In medicine the vista opening out before the doctor is so vast and alluring that it seems to us almost as if we were witnessing the birth of the science. In physics, our leading thinkers believe they are groping to a real understanding of the mysterious link that binds together energy and matter; in chemistry there are rumours that the dream of the alchemist of transmuting the elements has been achieved; and the engineer, while developing in all directions, is, at last, by the union of electricity and water power, appearing to enter into his richest heritage.

There is a theory of progress that I would like to put before you. I want you to imagine yourself standing at a vast distance away with a panorama before you of the world's history, and the means of estimating in numbers the condition of the world from the point of view of pro-

gress. Supposing we tried to plot this progress. We might measure units of time along a horizontal line, and units of progress advance along a vertical line. It may be that we should find that the world had advanced by leaps, or it may be—and to me the idea is a very attractive one—that its advance has been like a geometric progression sum. Whichever view you adopt, you come, I think, to the same conclusion that as the world gets older, it is hurrying on faster and faster to some great climax. I have tried to make my meaning clear with two diagrams.

The curve is the ordinary curve which results by taking such a simple geometric series as 2, 4, 8, 16, 32, 64, and so forth and measuring these values along the vertical line, while we measure the corresponding numbers 1, 2, 3, 4, 5 along the horizontal line. The curve is got by plotting the points at which perpendiculars from these lines would intersect. You will notice that I have used a larger scale for the horizontal line than for the vertical, so as to make the figure simpler to draw and to follow. The difficulty of appreciating the first six stages of progress is so great that I have had to leave out the first five sets of figures. If we look at the matter from the point of view that man has progressed by leaps, with stages of rest between the leaps, we get really to a similar result, for, if I read history aright, the leaps upwards are increasing in height as the years go by, while the periods of rest grow shorter and shorter, and it is only necessary to join the various peaks to get a similar curve. The point I wish to bring home is that to-day we must regard our world as being in the state of the right-hand of the figure, and in consequence we are justified in believing that in our own lifetime we shall see a degree of



DO WE PROGRESS BY DEGREES OR BY LEAPS?

Two ideas of progress are suggested by these diagrams. In the one case the advance is shown by a curve which represents an ordinary geometric sum, the periods of time being marked along the base line and progress along the vertical lines. In the other it is indicated in a series of leaps, the curve being drawn in such a way that the time periods between epochs of progress steadily decrease, while the amount of progress attained at the end of each period steadily increases

advance that will make the present appear to us a period as far removed from us as the time of the Tudors, or perhaps even that of the Normans, appears to us to-day.

All this is, of course, pure speculation, but there can be no doubt of the solid fact that the utilisation of water power to generate electricity is bound to have a very great influence on industrial development. One has only to mention the word water-power for the mind to think naturally of Niagara, for though several great schemes have been put into operation besides the harnessing of Niagara, the work done there has rightly fired the imagination of the world. Niagara yields by day and by night to Canada and America the enormous total of 580,000 horse-power, and as the methods employed at the Falls are similar to those in use in other parts of the world, a description of them will help us to realise the method by which man has succeeded in bringing the white coal, as water has picturesquely been called, into his service.

The Falls of Niagara lie on the border-line between Canada and the United States of America; they are divided into two by Goat Island, an island 75 acres in area, the Horseshoe Fall on the Canadian side being 2,600 feet in width, and having a drop of 169 feet, and the American Fall, which is of similar depth, being 1,000 feet wide. When one realises that the mass of water passing over Niagara is such that it develops the enormous total of 7,000,000 horse-power, it will be seen that the American and Canadian engineers have, as yet, only drawn on a bare fraction of the energy available for their purpose. In fact, the water that they use to drive the turbines that generate the electricity,

as its solitary effect on the Falls, has lowered the head of the water by between 2½ inches and 3 inches.

It was on April 4th, 1895, that Rudolph Baumann, a Swiss engineer, turned the wheel that started the generation of electricity at the Niagara Falls. To effect this, however, and still more, to make possible the present development of electrical power at Niagara, a vast engineering work has been required. The problem has been to cut within the cliff by the sides of Niagara a series of vast tunnels—penstocks, the engineers call them—through the solid rock.

The tunnels have had to be driven downwards the whole depth of the Falls to enable the turbines to take full advantage of the force developed by the falling water. They are lined all the way with brick and concrete, and as the water reaches the bottom it strikes the vanes of turbines, forcing them to revolve, and to turn with them the monster generators that develop the electricity. When the water has passed through the turbines, it must obviously be allowed to escape without any check, for otherwise, of course, it would exert a back pressure on the turbines, and nullify to some extent the advantage gained from having so vast a head of water. To indicate to some extent the magnitude of the task, I will quote you a few figures relating to the tunnel or tail race of the Niagara Falls' Power Company, which was the first to be cut. It is 7,000 feet long, and at its greatest section is 21 feet by 18 feet 10 inches. A thousand men were employed working at it continuously for three years, and they excavated in all 300,000 tons of rock, and used 16,000,000 bricks for the lining. For the wheel-pits at the base of the penstocks, 123,455 cubic yards of rock had to be excavated.

The simplest part of the whole scheme is the supplying of water to the tunnels. All that has had to be done is to build a wall slanting down stream, and to provide sluice gates and gratings to prevent the possibility of solid material getting into the turbines.

Canada and the United States of America have profited richly from their enterprise. Niagara itself has become the site of a large commercial settlement. When the power was first generated, it was only practicable to send it to Buffalo, 21 miles away, but now it has been carried to Syracuse on the east and to Toronto on the west, the towns being 250 miles apart. Already schemes of further development are on the way, and it will not be long before Niagara is furnishing power to towns that are 300 miles or more distant.

Naturally, one of the difficulties against which the engineers have had to contend has been the best means of carrying the power. Though Mr. Marconi, among other engineers, believes that the time will come when it will be possible to transmit power through the ether by wireless, it has so far been necessary to carry it on copper wires. When these pass through desolate country, the engineers are met with difficulties of all sorts. Valleys have to be crossed, wide paths have to be driven through forests, and precautions taken to prevent ill-disposed persons from stealing the copper wire that is used for the purpose. When you consider that the ordinary house supply of electricity comes in at a pressure of between 150 and 250 volts, you will get some idea of the tremendous height of the voltage by the statement that 100,000 volts is now a common pressure for it to be carried at, while electricians are con-

fidently looking forward to the time when even this voltage will be doubled.

From Niagara, let us pass to Puget Sound in the State of Washington. In the case of the Puyallup River, the engineers had no great falls of which they could take advantage, but they had a river which ran a riotous, precipitous course. A daring scheme in this case has been carried out. Far away among the pine forests of the mountain a low dam was built to bank back the water by a height of about 4 feet. From this reservoir two concrete walls were built out, lying 60 feet apart close by the river, and then curving, so as to run along its course and to get nearer and nearer together until at last they were only 8 feet apart. Here a gate was built with sluices, so as to ensure a steady supply of clear water. From this intake the engineers built an enormous wooden trough 8 feet wide and 8 feet deep, and they carried this trough on stout trestles for a distance of 10 miles along the mountain sides. You can imagine the engineering skill and resource required for this! At times the trough runs along the face of a cliff, which towers 500 feet above it, while below a dizzy precipice falls sheer to the river bed. Twice it had to be carried across a deep valley, and eventually it discharges its waters into a large concrete basin. You have guessed by now, I expect, the object the engineers had in view; while the river bed has a steep gradient, the trough goes over an easy gradient, just enough to ensure a steady flow, with the result that, when the water has reached the concrete tank prepared to receive it, it is 1,730 feet above the level of the river from which it has come, and into which it is going to be discharged. The engineers, in fact, have mimicked Niagara, with the differ-

ence that, whereas at Niagara the head is only a matter of about 170 feet, they have ten times that fall at their disposal. From the small concrete reservoir, the water is carried by eight steel pipes to the power-house. At their mouths, the pipes are 6 feet across, but as they reach the turbines, they narrow until they are only 3 feet in diameter. If you have ever felt the force of moving water, as, for instance, by bathing in a roughish sea, you will realise the enormous pressure that these pipes have to withstand. You have perhaps seen firemen struggling with a hose, and you have heard that it is an easy matter to knock a man down with a jet of water. To withstand this pressure, the great steel pipes have to be firmly anchored down at intervals of 125 feet. They discharge their water into the turbines waiting to receive it, and the electric power that is then generated is carried away on the wires, as at Niagara, to drive the machinery in the great towns in the district.

To describe the various plants in use for generating power would be an endless task. Switzerland has long ago taken advantage of its waterfalls; vast undertakings are at work in California and the West Pacific Coast; Mexico is exploiting its resources; in Norway, as we shall see later, a great new industry is being built up on the basis of water-generated electricity, while all over the Continent similar schemes are either working or projected.

In Great Britain, however, we have not yet taken full advantage of such facilities as we enjoy. It is true that at Kinlochleven, in Argyllshire, a large hydro-electric plant has been successfully employed, and that other falls have been harnessed, but if the views of engineers are correct,

we could, if we wished, enormously increase our stock of available power by tapping the water supplies of the Highlands. Mr. Alexander Newlands, the assistant engineer of the Highland Railway, has made a special study of this subject, and as it is a matter that intimately concerns the future, and even the present, prosperity of our country, the arguments he puts forward in favour of tapping the Highlands for power are of especial interest. Mr. Newlands opens the pamphlet he has written on the subject rather on the lines of an interesting paper published by the British Science Guild, where a careful analysis was made of all the possible sources of power, and he shows that the time must come when these will be exhausted. Now, it has been estimated by Professor Forbes, F.R.S., that the water power available in Scotland is, in all probability, sufficient to work the whole of the Scotch railways with a substantial surplus for other purposes. The water possibilities of Great Britain lie chiefly in the North and West of Scotland, where the rainfall throughout the year is fairly uniform, and amounts in many parts to the considerable total of 60 inches a year, and, in addition, the Highlands include many lochs with a rapid and easy fall to the sea. Further, particularly in the North and West Highlands, the drainage areas are all near the seaboard, which is so sheltered and indented as to afford peculiar advantages for access by shipping.

I have already referred to the Kinlochleven installation as one of those in the Highlands, but it is interesting, as indicating the considerable opportunities afforded in the North of Scotland, to notice that the reservoir built in connection with it is probably the largest artificial one in

Europe, being $7\frac{1}{2}$ miles long, and having an average width of $\frac{1}{2}$ mile. It can compound the huge total of 20,000,000,000 gallons of water, sufficient to give an output of 30,000 horse-power for about 100 days. The cost of the work was £600,000, or equal to £20 per horse-power. Commenting on this work, Mr. Newlands writes:

"With the exception of its high elevation and heavy rainfall, the Kinlochleven area is not more favoured than many areas of greater extent throughout the West and North of Scotland, and in many of them the expense of a dam would be unnecessary, owing to the presence of natural reservoirs or lochs in most of them."

As regards the future utilisation of this power, Mr. Newlands enters a caution. He regards it as probable that, owing to the interest that is now being taken in this source of power, development will proceed along lines of private enterprise, and he shows that if steps are not taken to insist that the various areas must be treated as a whole, a great deal of the power will be wasted through individual landowners making use of such small sources as would suit their individual requirements, and thereby employing the power wastefully. There can, I think, be no doubt that the proper thing to do would be to look on these power possibilities as a national asset, and to develop them by Government assistance, and for this it is probable that before long it will be necessary to have recourse to a Royal Commission.

Let us see now how this power compares as regards cost with the power we are at present raising from steam. Naturally, we have in each case to consider the circumstances affecting each particular installation, but,

broadly, the cost can be taken as being about 50 per cent. of the cost of steam, raised under the most favourable conditions, and electric power has been advertised before now at a rate as low as 30s. per horse-power per annum. Here are some striking figures taken from a fairly recent estimate that appeared in the *Electrical Review* as showing the minimum cost of power from various sources :

	£	s.	d.
Electrical horse-power per annum from water in Switzerland	1	19	0
Steam in England	4	11	8
Blast-furnace gas in Germany	4	1	7
Producer gas in England	5	0	0

A recent estimate has shown that the quantity of water power in Scotland amounts to about 1,000,000 horse-power, but supposing that we were to halve this estimate, and to put it at only 500,000 horse-power, this would represent an amount of power on a ten-hours' working day basis throughout the year equal to that obtained from 3,500,000 tons of coal, which is a twelfth of the total quantity raised in Scotland for 1911. Now, supposing that we estimate the price of coal at 10s. a ton, the 3,500,000 tons required would cost £1,750,000, an amount of money that it is surely worth while to save by harnessing the water power. These are the words that Mr. Newlands makes use of to drive his lesson home :

"It would almost appear, therefore, that these Highland water powers, which, as powers, are without the interference of any labour combination, should be laid under toll for the requirements of our industrial life. The market for our output is not next door, it is world-wide,

much of our raw material is imported, and the facilities for transport by land or sea, either to or from the North of Scotland, are already equal to those that exist in any portion of the British Isles."

There is an aspect of the utilisation of water power to which I should like now especially to direct your attention. It is ten years or more since Sir William Crookes warned us all that the world was in danger of an ammonia or a nitrate famine. To realise the meaning of the statement, we shall have to consider for a moment an aspect of the art of agriculture. In the very early days, man was an animal living off the produce of hunting. Then he appears to have realised the idea of pasturing flocks and herds, thereby increasing the numbers of his kind that a given area of land could support. His next stage—necessitated by the struggle for existence—was when he started tilling the soil. Passing beyond this, he realised the advantage to be gained from leaving his fields fallow for a period, and later discovered that it was even a better method to practise a continual rotation of crops. To-day we are living in the days of artificial manures, and of these one of the most important is ammonia or nitrate. The trouble is that crops require nitrogen in some such form for their existence, and are unable to make use of the pure nitrogen that is everywhere present in the air. Hitherto, apart from farm-yard manure, we have relied for our supply chiefly on the great salt bed deposits in such places as Chile and Peru; but about ten years ago, Sir William Crookes warned us that the time was not far distant when these supplies would give out, and appealed to the chemists to find some effective means of inducing the nitrogen of the air to enter

into combination with the oxygen and provide a supply of the nitrate that was wanted.

The chemists have responded nobly to the appeal, and, in co-operation with the engineers, have found a source of supply that seems indefinitely to promise us as much nitrate as we may have need of. Quite recently, Mr. Thomas N. Norton, an American Consul in Germany, brought out a most interesting volume in the Special Agents Series in the Department of Commerce and Labour in the United States on "The Utilisation of Atmospheric Nitrogen," and he showed the various ways in which the chemists had succeeded in getting atmospheric nitrogen to enter into the desired combination. The question barely comes within the scope of this volume, but as it is a subject of which we are all bound to hear more within the next few years, I will include a short account of it.

Mr. Norton starts his paper with a careful analysis of the present situation, and he concludes that there are only four ways of meeting the world's present demand for combined nitrogen. These are:

(1) By a temporarily increased supply of saltpetre from deposits, soon, however, to be exhausted;

(2) By an increased supply of ammonia as a by-product of coal and peat, dependent on a general reform in the use of these materials, as held and limited by the extent to which they may be used as sources of light and heat, and limited, further, in point of time, by the world's supply of fossil fuel, with a possible exhaustion within a few centuries;

(3) By the closest economy in preserving all waste forms of combined nitrogen, vegetable or animal, so that they may be utilised as plant food;

(4) By the technical transformation of atmospheric nitrogen into combined forms available for the needs of agriculture and the arts.

Whilst there are undoubtedly possibilities in the second and third of these methods, the general opinion among scientific men is that the time has come when the best talent must be directed to solving the problem of utilising industrially the nitrogen of the air.

With the method of Professor Haber we need not concern ourselves. He has succeeded by chemical means in inducing the nitrogen of the air to combine with hydrogen to form ammonia, and the process with its modification is now under the control of one of the great German syndicates.

Another method of utilising atmospheric nitrogen as a source of plant food interests us closely, for it consists of inducing the nitrogen of the air to combine directly with the oxygen to form nitric acid, and so by a simple process to form nitrates. It will, I think, be sufficient for our purpose if we trace the story of one of the means by which this can be done. In 1785, the great scientist, Cavendish, made the discovery that when electric sparks were passed through air, an acid was formed. Seventy odd years later, in 1857, Bunsen discovered that the acid thus formed was nitric acid. Various experiments were made, and it was eventually found that if an electric arc is placed under the influence of a powerful magnet, the arc of flame is turned into a great disc of flame, and that as air passes through this flaming roaring electric discharge, nitric acid is produced. It is perhaps hardly necessary to say that on the basis of this discovery, numerous processes have been

patented, and are now being worked. To quote only the exploitation of a single method, we will consider the works that have been erected at Notodden. In 1906, a dam was constructed to give a fall of water of 165 feet. There is a big volume of water there, amounting to a flow of 75 cubic metres a second. The water passes to four vast turbine generators, each of 10,000 horse-power. As you can imagine, power of this dimension has to be handled carefully, and to carry it there are four separate lines, each consisting of six cables, 12 millimetres thick.

I should add that the chemists have not contented themselves with the working out of this principle alone, but have introduced others, some of which do not necessarily demand the use of the electric current. I have introduced the subject for two reasons, partly to give praise to the energy of the chemists who have succeeded in solving the question of the world's future food supply, and partly to show the enormous importance of utilising the great natural stores of energy that are at present going to waste. England owes much of her prosperity to the fortunate fact that, at a critical period of the world's history, she discovered that she contained great coal-fields, lying close to great deposits of iron. It is to no small extent on this great natural advantage that she has been able to build up her Empire and reach her position of dominance. We know full well that our stores of coal cannot last us for ever, and it behoves us to utilise to the full the great natural advantages that we possess in water power. There can, I think, be little doubt that the future of the world must lie with those who own the great sources of power, whether they are forced by circumstances, as we have been, to spend

it as capital, or whether, as in the case of the utilisation of water power, they can regard it as income. It may well be that the next 200 years will see the gradual development of those districts which enjoy great natural sources of power in water, just as it may happen that the deserts, with their scorching sun, may become densely populated regions. Man's predominance both over Nature and his own fellow-men has always been dependent on his control of power interpreted in its broadest sense. The power may be intellectual, moral, or physical, and if we are not to be left behind in the race, it is our bounden duty to our descendants, if not to ourselves, to strain every nerve to take full advantage of such opportunities as lie before us. It is only on those terms that a nation can survive, and it is not easy to see on what other grounds its continued existence could be justified.

CHAPTER XIII

TESTING—WORK AT THE NATIONAL PHYSICAL LABORATORY —A NEW SYSTEM OF DETECTING STRAINS IN ENGINEERING MATERIALS

One of the least easy ideas to drill into the mind of the boy who is starting a course in science is the point that measurement—and accurate measurement, at that—is the real foundation of science. It is only necessary, however, to study the development of scientific knowledge to realise that from the earliest times of which we have knowledge measurement has spelled progress. The Greek philosophers, and after them, Lucretius, were groping at the atomic theory, to quote but one example, but their imaginings remained mere speculation until, nearly 2,000 years later, men began to measure exactly what happened, and the atomic theory was born.

You may regard engineering as an Art based on the science of accurate measurement, and you will find few engineers to quarrel with your view. The bridge builder, the dam builder, the railway line constructor, and, in fact, the engineer generally, all have to study accurately the amount of expansion and contraction that the work on which they are engaged will undergo under the influence of heat and cold. They have to measure and determine the stresses and strains to which their buildings will be sub-

jected. They must take their observations with so minute a degree of accuracy that they can start boring from the two sides of a hill, and so arrange their work that the men on either side will meet in the centre with an error of not more than an inch or two. They must study their materials and know exactly how they will behave, whether they are exposed to arctic cold or tropical heat. They must, in fact, be men who can measure with exactness anything, no matter what it may be, with which they are brought into contact.

To indicate to you in a small way the accuracy demanded of the working engineer, I will tell you a striking story of engineering work that I heard only recently. The problem was the setting up of a large cylinder in a battleship. In this a piston had to move up and down, and the work had to be so exact that the extreme accuracy of 1,000th of an inch had to be reached, for on its perfect truth depended the power of the vessel to direct its gun fire. The engineer in charge, realising the responsibility of his position, took all precautions. He made his measurements, and to ensure there being no possible mistake, he even went so far as to polish the steel bed on which the cylinder was to rest. It took weeks to install, and at the end it was found to be out of truth and useless. The firm responsible for the work were not unnaturally annoyed, and justly enough determined to settle where the blame ought to rest. The work was dismantled under supervision, and at the last it was found that the responsibility rested with one of the workmen, who, carelessly sharpening a pencil, had allowed the shavings of the pencil to remain on the polished bed on which the cylinder was to rest. I have quoted this story

as it shows, I think, in a striking way the extreme accuracy that may be expected of the engineer.

The British Government have realised somewhat tardily the importance of this work of testing, and after many years of delay have found the money necessary to establish and equip the National Physical Laboratory at Bushy House, Teddington. The credit for the original idea belongs really to the Germans, Werner von Siemens and von Helmholtz, who induced their Government to found such an institution during the years 1883–7. Sir Oliver Lodge, as President of the Mathematical and Physical section of the British Association, urged that such an institution should be established in this country, but though a committee met and discussed plans, nothing was done. Four years later, Sir Douglas Galton took the matter up again in a paper before the same section, and a petition to Lord Salisbury resulted in the appointment of a Treasury Committee, under the chairmanship of that famous veteran of science, Lord Rayleigh. The report of the Committee was unanimous: "That a public institution should be founded for standardising and verifying instruments for testing materials and for the determination of physical constants."

An invitation was sent to the Royal Society to give effect to the finding of the Committee, and eventually Bushy House, which till 1896 was the residence of the Duc de Nemours, the son of King Louis Philippe, was selected for the purpose.

Owing to the dramatic circumstances attending the collision between the *Olympic* and the *Hawke* in the Solent, the feature of the National Physical Laboratory that has appealed most strongly to the public has been the erection

and equipment of the great experimental tank that the nation owes to the public-spirited generosity of Mr. A. F. Yarrow, who, in 1908, offered £20,000 for the building of such a tank, provided that a sum of £2,000 a year should be guaranteed for a period of ten years for its upkeep. The Institute of Naval Architects responded to this offer by guaranteeing £1,340, and the Executive Committee of the Laboratory undertook to find the balance.

A visit to the tank is of exceptional interest. It is a great sheet of water, 550 feet long and 32 feet wide, with another smaller tank beside it. The track and its carriage, designed to draw the models of ships that are being tested, runs down the whole length of the tank, and the construction of the track was undoubtedly the most difficult part of the work. Special arrangements had to be made to prevent the rails giving under the weight of the 14½-ton carriage that has to draw the model vessels, as it was felt that any irregularity of this sort must interfere with the accuracy of the experiments. The levelling of the rails again was a work demanding extreme care, the method adopted being to connect two jars of water placed 40 feet apart by a rubber hosepipe. Needle points dipped into the water of the jars, and when the reading of the screws adjusting these exactly tallied, the constructors could know that they had got a level true to the 1000th part of an inch. The work of adjustment alone occupied four and a half months, and it was possible to certify at the end of this period that there was no measurable departure from a straight line. The extraordinary degree of exactness reached can be appreciated by considering the statement that one of the factors that had to be taken

into account in the levelling was the curvature of the earth's surface.

All sorts of precautions had to be taken as regards the carriage running over the tank. It is no easy task to secure absolute uniformity of speed. Each wheel is furnished with its separate motor to drive it, and each had to be ground on its shaft to ensure a uniform diameter, the degree of accuracy guaranteed being a maximum variation of 3-1000ths of an inch. Naturally, the carriage is fitted with all sorts of measuring instruments, and with special devices for starting and stopping. The power to drive it is derived from a battery of 55 cells, so arranged that extra cells can be switched in to ensure the current remaining constant while the carriage is getting up speed.

The points I have mentioned about the tank are not those that strike the visitor. He is surprised rather by the immensity of the tank and by the ship models that, if he is fortunate, he sees in course of construction. I should like to be able to speak of tapering masts and trued-up rigging, but the ship models worked on at the tank are very different from those that you see in the shops. They don't carry masts, and, instead of being made of iron or wood, are built up out of paraffin wax. It makes a great difference to a ship's speed how her hull is constructed, and one of the chief problems to be determined by those in charge of the experimental tank is the precise behaviour of the different shaped models designed by naval architects. When the question of the *Olympic-Hawke* collision arose, the problem was set to those in charge of the tank to determine to what degree such a force as suction existed between two passing vessels.

I am anxious that you should get a good idea of the variety of the work that has to be undertaken by such a laboratory as that at Bushy Park, and we will, therefore, go through a year's report of the different departments, referring to portions of the work carried on in each. Electrical work is given the place of honour in the report, and we note that the department is still busily engaged in the work of standardising, trying to eliminate possible causes of variations and error in one of the electrical machines. The Japanese Government, we see, have appealed for some accurate standards of electrical resistance, and the director explains how they have been manufactured. One of the problems before physicists almost since the earliest days when electricity was scientifically considered has been to get a standard electric cell—one, that is, that at any given moment can be used as a standard of electrical pressure or voltage—and in the course of the year in working at this problem, the department has kept 300 of such cells under constant observation, and report with satisfaction that they remained true to the extent of one or two parts in 100,000. We will leave the department at that, contenting ourselves with the observation that a whole lot of similar work was in regular progress, and that it, like the other departments, was in constant touch with German and American standard laboratories, the three laboratories giving a constant interchange of material.

Electro-technics comes next on our list, and the first thing we notice is that this department, too, is striving after a satisfactory unit—that of light. Not much interest in that, you may think. But let us leave the laboratory, and see what an accurate standard of light means. A few

years ago I was present at the birth of a new society, the Illuminating Engineering Society. It is a body founded by the amazing energy of Mr. Leon Gaster, and Mr. Gaster has again and again impressed upon me that the basis of the work that he and his society are able to do is that he has got a practical handy means of measuring the intensity of light in any part of a room, or mine, or factory. Mr. Gaster is an engineer, and does not pretend to work with the absolute degree of accuracy that is demanded for the theoretical purposes of physics, but all his work has to be based on the accurate investigations of the physicist. As a result of this power of easily measuring light, it has been shown that that terrible eye disease of miners, nystagmus, which is responsible in all probability for many of the mining disasters, owing to the miners being unable to recognise the first signs of danger, is due to deficient illumination in the mines. He and his friends have found, too, by measuring the light in the different factories, that deficient light is responsible for many of the terrible accidents we read of from time to time in the factories. By having a satisfactory means of telling people exactly what intensity of light they have in the various parts of their schools, he can inform the authorities when their school-rooms are such that the eyesight of the children is being ruined. These are but a few of the activities of a society which depends ultimately for its efficiency on such accurate work as that which is being done at the National Physical Laboratory. And international standards are essential if the work of different countries is to be compared.

Under the heading "Visibility of Lights," we come to

a very interesting piece of work. You have only to read the newspapers to hear of cases of collision at sea, where it has been shown that the lights of one or other of the vessels have not been visible until too late to avoid a collision. All sorts of interesting points have been determined in connection with this research. It has been shown, for instance, that some of the red glasses used in ships' lanterns cut off the enormous majority of the light given by the burner, while others are efficient. It has been determined just how far off a light of a given power can be seen—an important point, you will agree, when I tell you that the Board of Trade regulations lay it down that a ship's lights are to be visible for a distance of at least two miles. The regulations of the different lights are similar, so I will quote the shortest of the regulations, which reads: "A steamship, when under weigh, shall carry: On the port side, a red light, so constructed as to show an unbroken light over an arc of the horizon of 10 points of the compass, so fixed as to throw the light from right ahead to two points abaft the beam on the port side, *and of such a character as to be visible at a distance of at least two miles.*" The investigations at the laboratory showed that in several cases the lights supplied commercially were not such as to satisfy these conditions as to visibility. Among many interesting results determined in connection with this piece of work were such facts as that the use of spectacles made it at times curiously difficult to pick up very faint-coloured lights. The researchers also took great pains in determining details about the way in which a distant light is picked up more easily if it is looked at obliquely than if it is looked at direct.

Most of us who have to pay the bills for electric light and heat in our houses have reason at times to dispute the accuracy of the meters registering the amount of electric current consumed, and in this department in the year in question many tests were undertaken to see how far properly made meters varied owing to the vibration of railway journeys and the different types of work that they have to perform. Various experiments were undertaken, also, with a view to procuring a more accurate measurement of heavy currents.

In the chapter on cable-laying I shall point out that the first Atlantic cable failed after it had been in use for only a short time, owing to the breaking down of the insulating material in which the conducting wire was enclosed. A great many results on this subject have, of course, been obtained experimentally, but with a view to determining what would happen in the case of a very high voltage cable in New Zealand, where the cable would be subjected to severe strains of weather, an elaborate research was undertaken for this specific object, and a general research on the subject was also carried out for the Engineering Standards Committee. At the requests of manufacturers, too, the Laboratory carried out a series of tests on special kinds of alloys; and here I may remark that anyone who doubts the value of the work at the Laboratory is immediately answered by the fact that the authorities are continually being asked by a greater and greater number of manufacturers to undertake special investigations on their behalf.

Leaving the department of electro-technics, we will go on to thermometry. Thermometry, with the high tem-

peratures in use at the Laboratory, is one of the most fascinating of the departments. Not content with measuring intense cold, the physicist insists on being able to get an accurate measurement of high temperatures. This is not the place to go into details of high temperature measurements, of how the temperature is gauged by the colour of a molten metal, or by the electric current caused by the heating of two metals with their ends in contact. We will only notice here that the idea was to try to get a gas thermometer that would register the enormous heat of 1,500 degrees temperature on the centigrade scale of the thermometer, a heat, of course, far above that at which the glass used for ordinary temperatures would be a liquid, some aspects of the problem being to get a transparent substance that could be made into tubes, that would keep the gas in and make it possible to see how it expanded and contracted under the influence of heat. The research led the investigators to a curious conclusion which they published at the Royal Society. They found that if they heated a carbon furnace to a very high temperature and had a brass water-cooled tube inside, an electric current of considerable amount was produced, and, tentatively, they made the inference that they had found a means of turning heat direct into electricity. It is too early as yet to say whether the discovery is of any practical importance, but it has, of course, long been a dream of engineers to turn heat direct into electricity without its being necessary to have recourse to the roundabout method of steam and dynamos. The department also occupied itself with the methods of determining the flash-point of illuminating oils. It is work such as this that has made it

a very uncommon thing to read of the terrible explosions that used to be so common with oil lamps. If a lamp upset in the old days—the accident happened sometimes without the lamp upsetting—it too often put the whole place ablaze, but regulations based on such experiments as these have been introduced which insist that the oils used in lamps shall have what is called a high flash-point—that is to say, that neither they nor their vapours shall take fire until the temperature reached is considerable.

Few questions are more important in connection with our food supply than that of cold-storage. Powerful engines have to be employed to keep the plant going that supplies the cooling gases and liquids for the pipes, and obviously great economy can be effected if a means can be devised to prevent the heat of the outside air passing through the walls of the cooling chamber. One of the enterprising firms dealing with this class of work decided that enough was not known as to the power of such substances as coke, charcoal, slag-wool and so forth to keep out a flow of heat, and the Laboratory was invited to carry out a series of tests on this point.

I have said so much in this chapter about the importance of measurement that you will not be surprised to hear that the Laboratory has a special department of metrology. Instead of going through their actual work, which includes, by the way, the testing of the taximeters on taxi-cabs, and, of course, involves work of scrupulous nicety, I will merely give you a single illustration of the extraordinary degree of accuracy to which the units of length, for instance, are constructed. The surfaces of

some of these measures are polished to such a supreme degree of accuracy, that when they are brought thoroughly into contact without there being the slightest layer of air in between them, it is a recognised fact that if they are pulled forcibly apart the metal itself will often break in preference to the measures parting at the original surfaces. You may be interested to know that the explanation of this is that the two surfaces have been brought so closely together that the particles or molecules of which the substance is composed are able to exercise an attraction on one another, just as they do in an ordinary lump of material. It is an illustration of the force of cohesion, and if you come to think it over, you will realise that it is a very extraordinary force indeed that holds a lump of substance together instead of letting it fall apart like loose sand, the molecules, of course, being millions and millions of times smaller than the smallest grain of sand you can conceive.

We will pass over the Optics Department, and content ourselves with a mention of the wonderful tide-predicting machine that, by a complicated system of wheels and cords, will predict for you the state of the tide at any port in the world you like to mention at any future date, and see what the Engineering Department of the Laboratory is occupied with. You will remember the terrible disaster of the Tay Bridge, where a gale of wind blew down a portion of the bridge, and a trainload of helpless passengers were hurled to their deaths. Well, one of the researches of the department has been to determine just what force the wind is able to effect on different types of structures. They have been working, too, to determine how the different

materials react to stresses of different direction and of high frequency. You all know that a possible accident to a bicycle—very rare now in these days of clever construction—is for the parts that have been welded together to come apart. Well, this happens with bigger things than bicycles, and the whole question of welded joints has been studied at the Laboratory. All such points have had to be considered as the size of the welded surfaces and the methods employed in welding, and the department has expressed its opinion in the following terms:

"The broad conclusion of the investigation is that in important work, where the failure of any particular welded joint may involve serious damage to the structure, the subjection of each joint to a proof-load is still desirable. Further, there appears to be no evidence that the want of uniformity in the material which is usual in the region of a welded joint is liable to cause failure of the joint under repeated applications of the load, provided the weld be originally sound."

Now we come on to aeronautics. The lives of aviators are, to some extent, in the hands of the Bushey Park investigators. It has been their duty to plan experiments to determine what the forces are that act on various parts of the aeroplane wings, to find out by trails of smoke how the air flows round them, to learn what is the resistance of wires and ropes. They have placed models of dirigibles in water, and seen how the water eddies round the surface just as the air eddies round the dirigible. The effect of different propellers has been studied with measuring instruments at work the whole time. Motors suitable

for dirigibles have been subjected to all sorts of trials; the mechanical strength of the different fabrics used has been determined. Elaborate tests have been made, too, as to how far they allow hydrogen to leak through them, as to their capacity for absorbing water, their durability and weathering properties, their alteration on exposure to ultra-violet light, their properties as regards heat transmission, inflammability, and their behaviour towards extreme cold. Tests have also been made on the suitability of different kinds of material for the framework of airships and aeroplanes.

Roads, too, have been the subject of investigation in the Engineering Department, the attention of the workers being directed, among other points, to mechanical tests on road materials, to the way in which the various materials wear away by rubbing on each other, to the influence of a falling ram that imitates the countless shocks delivered to roads by the pounding of horses' feet and by the wheels of vehicles, to the qualities of cementing material and to endurance tests on specimen roads. At the request of the engineers to the Road Board, a special series of tests was made on samples of pitch supplied to the Road Board specifications.

We will conclude our visit to the Laboratory by a glance at the work they undertake in metallurgy and metallurgical chemistry. The development in alloys so closely concerns the engineer, and has been so astonishing in recent years, that it is impossible to forecast what intensely interesting results may not follow by further investigations on these lines, and numerous experiments have been conducted on alloys, especially with aluminium

and copper, and with aluminium, copper and zinc. Special work has been done, too, on the effect of heating steel to high temperatures, on determining the melting point of iron, and on the effects that strain exercises on metals at high temperatures. It is only necessary to consider the various engines that are at work to realise the importance of this work and of another series of experiments conducted on the causes of brittleness in steel. In this research the singular conclusion appears to be justified that the brittleness may be due to the presence of carbon dioxide. The metallurgical chemists, in addition to other valuable work, were able to report the amazing and very significant conclusion that on exposing charcoal to a current of air containing 5 per cent. of sulphur dioxide, spontaneous combustion occurred even at the everyday temperature of 64° Fahrenheit. The experiments—which were undertaken at the request of Lloyd's Register—show clearly the danger of fire involved in using this gas for disinfecting purposes in places where charcoal is used in the walls. From this the workers passed to a study of the behaviour of decayed wood, but the experiments appear to indicate that this material is markedly less inflammable under these conditions than charcoal.

In the preceding pages I have only been able to glance at a portion of the work that is undertaken yearly by this great Laboratory; and to indicate from another point of view the volume of work done, I am including a table showing the work done in the verification of various instruments in a single department, Physics. They are copied direct from the director's report for the year 1911:

Comparison of Tests made During the Years 1909, 1910, 1911
Physics Department

Electrical Measurements

	1909	1910	1911
Condensers and Specific Inductive Capacities	7	18	32
Magnetic Permeability ..	13	—	11
,, Hysteresis	17	7	25
,, Ageing	2	—	1
Total Loss (Hysteresis and Eddy Currents)	28	32	84
Inductance Tests	9	10	9
Standard Cells..	72	99	100
Telephone Cables and Loading Coils	6	2	1
Tuning Forks	—	3	—
Frequency Meter	1	—	4
Wavemeter	—	1	1
Miscellaneous	—	—	1
	—— 155	—— 172	—— 269

Electrotechnics

Resistance Coils	42	76	162
Resistance Boxes	76	63	125
Testing Sets	26	45	44
Conductivity Tests	53	29	54

	1909	1910	1911
Insulation Resistance ..	86	25	63
Dielectric Strength	82	86	252
Ammeters	313	464	521
Voltmeters	232	372	447
Ohmmeters	63	54	85
Supply Meters	331	391	280
Potentiometers	1	10	8
Wattmeters	34	20	20
Galvanometers	1	4	2
Shunts	3	20	41
Primary Cells	200	93	78
Secondary Cells	—	9	—
Fuses	777	21	—
Resistance Alloys	1	4	4
Transformers	2	7	4
Switches and Circuit Breakers	—	1	2
Miscellaneous	5	16	11
	——2,328	——1,810	——2,203

Photometry

Pentane Lamps	3	10	3
Incandescence Lamps ..	895	440	886
Arc Lamps	3	1	—
Ships' Lamps	—	22	27
Photometers	1	—	2
Gas Burners	11	—	—
Miscellaneous	—	7	2
	—— 913	—— 480	—— 920

Thermometry

	1909	1910	1911
High Range Thermometers ..	186	140	109
Low Range ,, ..	15	83	68
Open Scale ,, ..	51	135	150
Flash-Point ,, ..	—	—	104
Resistance ,, ..	8	7	3
Melting Points	5	—	4
Thermocouples	12	19	19
,, with Indicators	3	7	10
Pyrometers	55	61	84
Heating Appliances	2	—	—
Flash-Point Apparatus ..	13	39	27
Miscellaneous	18	5	4
	—— 368	—— 496	—— 582

Optics

Photographic Lenses	13	4	8
,, Shutters ..	21	13	27
Optical Constants	—	—	4
Prisms	1	—	—
Absorption Tests	8	—	8
Trial Case Lenses	3,579	5,285	5,030
Clinometers	3	4	28
Prism Binoculars—Loss of Light	8	—	—
Miscellaneous	3	2	1
	——3,636	——5,308	——5,106

Metrology

Line Standards and Scales ..	19	32	8
Tapes and Wires			23
Coefficients of Expansion ..	9	32	48

	1909	1910	1911
End Gauges			129
Cylindrical Gauges			185
Screw Gauges, Taps, etc. ..	865	229	197
Gauges of Special Type ..			2
Templates (Sets)			25
Other Length Measurements	—	15	89
Micrometers, Callipers, etc. ..	5	5	2
Measuring Machines	1	2	—
Cathetometer	—	—	1
Lead Screw	—	—	1
Areameters	—	5	6
Gauging Instruments for Casks	—	—	60
Measures of Capacity (Glass Vessels, etc.)	809	618	926
Chemical Weights	479	878	1,205
Densities	20	38	27
Artificial Ageing of Invar ..	1	2	5
Miscellaneous	1	4	35
	2,209	1,860	2,974
	9,609	10,126	12,054

Taximeter Testing (*Metrology Department*)

Taximeters	7,985	13,918	12,852
Taximeter Gear Boxes ..	2,180	4,445	4,811
Taximeter Flexibles	13	3	2
	10,178	18,366	17,665
	19,787	28,492	29,719

Now that we have seen something of the work that is being undertaken at the National Physical Laboratory, I propose to conclude this chapter with a short account of a new method of testing engineering materials that is, I think, unsurpassed for ingenuity and beauty. You will have realised by now that when an engineer sets out to design a structure, it is very necessary for him to have a clear idea of the exact way in which strain will be brought to bear on it, and of the amount of the strains and stresses that it will have to support. Mathematical calculation and the results of physical research help him in his task, but cases from time to time arise where the conditions of the problem are so complex as almost, if not quite, to defy mathematical analysis. Obviously, it would be of enormous assistance to him if he could have a transparent model so constructed that by looking at it he could see the distribution of the stresses and strains. Many attempts have been made with this object, and models have before now been constructed in indiarubber, jellies and such-like substances, which, by yielding in those places where the strain is greatest, inform the engineer what parts of his structure he must be at pains to strengthen.

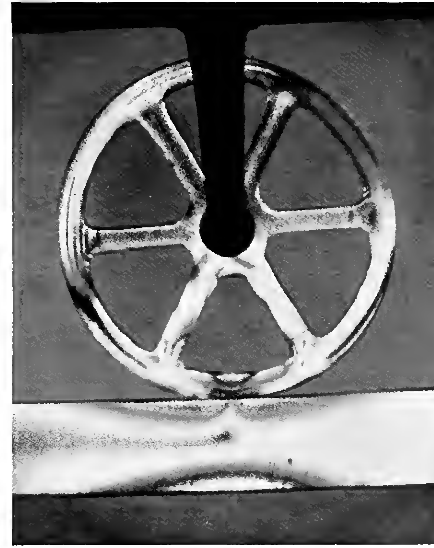
Professor E. G. Coker, the Professor of Mechanical Engineering in the City and Guilds of London Technical College, Finsbury, may fairly claim to have done a great service for engineering by his researches on the behaviour of transparent models to beams of polarised light as they are passed through it. The transparent substance he uses is xylonite; it looks very like sheets of talc, or, if you are not familiar with that material, you will get a fair idea of its appearance by regarding it as similar to the sheets

of horn that you see let into the hoods of motor-cars. As a matter of fact, it is a preparation of nitro-cellulose. Out of this he constructs models, as, for instance, wheels, springs, hooks, nuts and screws, girders, chains, pillars and so forth.

Now light, as you may know, is composed of waves coming through the ether at enormous speeds. The waves are quite unlike those of the sea, and if you want to try and form a picture of them, you would have to think of them as waves moving, say, from east to west, while the crests oscillated to and fro in the directions north and south. This would form a very imperfect picture of what occurs, for the waves of light are also moving in all sorts of planes. Means have been found, however, to polarise it—that is to say, to get rid of all waves except those moving in one special plane. To describe polarised light more accurately would involve our going into the theory of light a good deal more deeply than I care to do or than you would care to follow me, and I want you to accept my statement that with light properly polarised it is only necessary to send it through such a transparent substance as xylonite for its wave length to be altered, wherever the xylonite is strained, and for the model to appear a veritable blaze of colour. That, you might imagine, is not very much good, but when I tell you that Professor Coker can tell from the different colours exactly the extent of the force that is tending to pull any portion of his xylonite apart, or that is tending to compress it, you will easily realise the value of the method. The editors of *Engineering* have given me leave to reproduce a few of the coloured plates used to illustrate an article written by Professor


A wrench turning a nut


A hook with weight attached


A wheel on a rail

A NEW METHOD OF TESTING STRAINS

By Permission of E. G. Coker, D.Sc., F.R.S.E.

Coker for that journal in January, 1911, and these will show you the sort of appearance that you see on the screen when polarised light is passed through the models. The pictures fall far short of the actual beauty of the demonstration. I have had the advantage of seeing it both when Professor Coker demonstrated it at the Royal Institution and when he demonstrated it before the Optical Convention. The first thing one sees is a plain image of the wheel, or hook, or beam, or whatever he is showing. Then he starts putting on the pressure, and the models begin to develop all sorts of beautiful colour, changes occurring as the stresses vary. From the plates I have reproduced you will see for yourself how extraordinarily unequal the distribution of pressure is in such a simple case as that of a mere beam. Then, too, when you make a notch in it the whole picture alters, as you can see from the plate. The ordinary bolt nut and its screws are far from presenting the simple problem you might imagine them to do. There is a very complex distribution of forces, too, about a pillar that is bearing a load or the springs of a locomotive.

Many of you, I am afraid, may not have the opportunity for some time of seeing these experiments for yourselves, for in science, as in other departments of life, ideas travel slowly; but you will find that you can get a very fair idea of the play of the colours obtained with these models if you ask a geologist to let you see under his microscope a rock-section illuminated by polarised light.

After illustrating the application of his work to engineering problems, Professor Coker has appraised their value as a means of education, and has written:

"In addition to their value for experimental investigations, optical methods appear to have a certain amount of value for educational work. It is probably a very common experience that engineering students rarely show the same degree of enthusiasm for the study of the theory of elasticity as they do for the study of other branches of science, such as heat engines, for example. It is difficult to realise what is the internal condition of beams, shafts and the like when they are bent, twisted, or otherwise stressed; and the average student, especially if he comes direct from school, does not readily grasp the meanings of the symbols he uses, or the significance of the formulæ he obtains, because of lack of illustrations of the nature of internal stress. With a limited amount of experience, it seems quite safe to say that the pictures which optical experiments present to the eye afford a measure of help to students, whether they are intelligent workmen or the more systematically trained students of an engineering college."

CHAPTER XIV

STEEL—THE WORK OF THE FOUNDRY—HOW A COMMON FILE IS MANUFACTURED

In writing of steel it is impossible altogether to escape from the charge that one is commonplace. It is true, fundamentally true, that we are living in the steel age, and that it is steel that has made our civilisation possible; there are few among us who have not made this observation for ourselves, and none, I should imagine, who have not heard it made. In a book of this sort, however, the fact is brought vividly before you, for I should think there is not a chapter here in connection with which steel is not the leading feature.

Familiar as steel is to all of us, there is no one who has yet been able to find a definition to cover it exactly, though hundreds of experts have attempted to do so. For our purposes, however, it will be sufficient if we realise that steel is iron mixed with carbon, tempered to a certain degree of hardness. It is an easy matter to write "tempered to a certain degree of hardness," but do any of us, I wonder, realise the amazing range of the properties of steel? You get it sometimes so brittle that it will snap at the slightest provocation; at others so supple that it will buckle under its own weight. One is conscious that it can be springy and robust, for how could it otherwise bear the innumerable strains it is subjected to when

designed as springs for carts, and motor-cars and railway trains? It may be so pliant that it can be bent about in wire, or so keen that it will preserve its cutting edge, even though it is at a red heat. It is equally adapted for the crude-edge pick of the miner, for the grindstone edge of the backwoodman's axe, or for the amazing keenness of edge that can be put on the surgeon's knife. These various properties depend partly on the nature of the tempering—that is, of the way in which the steel has been allowed to cool, and partly on the substances with which the iron in it has been combined, such, for instance, as carbon, manganese, tungsten, chromium, and nickel.

Let me try to sketch briefly the processes to which iron must be subjected before it reaches the final stage of manufacture. There is little romance usually about the mining of its ore, for as often as not it can be dug in surface mines. Anyway, we start with it packed with its various impurities in railway wagons to go off to the foundry. A marvellous place the foundry is, too! Iron ore and lime and coal are all tipped together into an enormous furnace, into which a miniature whirlwind can be blown, the object being to get such a high temperature as will burn out the impurities from the molten ore. The coal supplies the necessary heat, the lime seizes hold of the silica that is present, and at the end you have a furious white-hot furnace covered by scum, the lime and the silica and the earth portions all rising to the top of this monster kiln, while the iron is boiling furiously below. When the process is at an end, the furnace doors are opened, and the iron pours out into sand moulds placed ready to receive it,

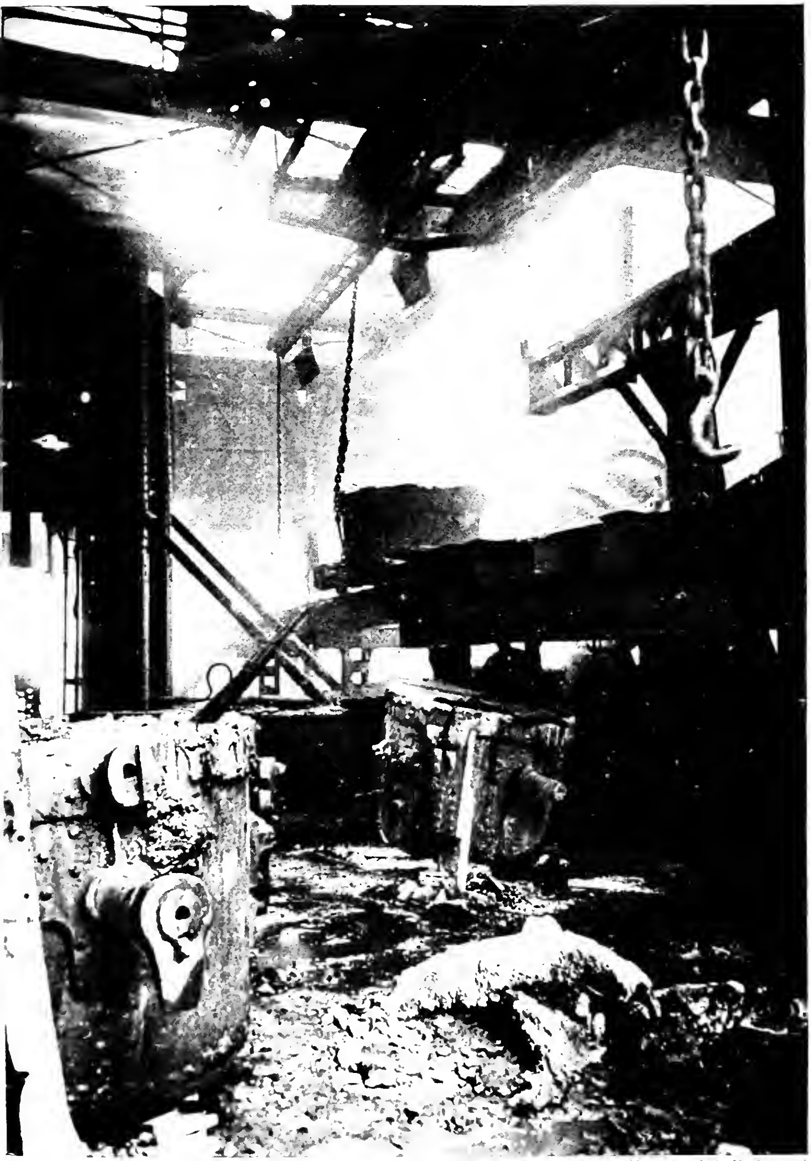


Photo: Underwood & Underwood

STEEL WORKS AGLOW WITH HOT METAL

the heat of it being such that it is only from a distance that you can gaze on its dazzling surface. Like most first processes, the iron—pig-iron it is called—is a crude enough substance now that we have got it, and it is taken away to another furnace, heated again to a white heat, and then "puddled" or stirred by great iron bars to rid it still further of its carbon and other impurities. In the manufacture of steel, as in all manufactures, we really come back to the same principle—"take a clean test-tube." If you are to get a definite product, you must have a pure substance to start with. In the wrought iron, as the iron when it has been puddled is called, you have the raw material of steel; in fact, so difficult is it entirely to eliminate carbon from iron that there is chemically no difference between wrought iron and mild steel. Steel commercially known as such contains anything from ·3 per cent. to 2·2 per cent. of carbon, and then by a curious irony of nomenclature, if the carbon content rises further, it is known as cast iron.

Henry Bessemer is the father of modern steel manufacture. Having made the discovery that an intense cold blast driven through molten pig-iron was most successful in producing steel, he proceeded forthwith to exploit his discovery, and thereby he laid the foundation of the greatness of Sheffield steel. His chief difficulty was with phosphorus, and when this, a few years later, had been surmounted by lining the furnace with lime, which combined with the phosphorus, forming incidentally a valuable manure, the essentials of steel manufacture had been completed.

It is an amazing fact how difficult it is for a new idea

to force its way to the front. I have a theory that I would not like you to press too far that the entry of a new idea gives the brain of most of us the same sort of pain that we feel on the cutting of a tooth; whereas, we welcome the various modifications of an old idea with the readiness with which we like to exercise our healthy muscles. Bessemer found this to his cost. The steel rails he manufactured were more expensive, but they had far more wear in them than the old iron rails, and the railway companies would not adopt them for the ridiculous reason that the engine wheels would be unable to grip them. The platelayers solved the difficulty, for the Sheffield firm that had adopted Bessemer's process induced them to replace the ordinary company's rails with Bessemer rails, and when the engineers had the success of the new rail thus demonstrated to them, they gladly capitulated. It is amazing, though, the difficulty that an inventor meets with, even though he has an invention that will save the user money.

I have tried in the pictures with which this chapter is accompanied to give you some conception of the wonderful processes necessary in the manufacture of steel, but you will naturally wonder how it is that men can approach sufficiently near to such vast blocks of white-hot steel as are necessary for the armoured warships, for instance. The answer to your question is that no man ever does go near them, even when they are red hot. What happens is that the white-hot casting is brought automatically on to a floor covered with rollers that can move in different directions. A man presses one lever and then another, and the sheet of dazzling steel moves this way or that to the rollers that are waiting to press it into shape. It is a

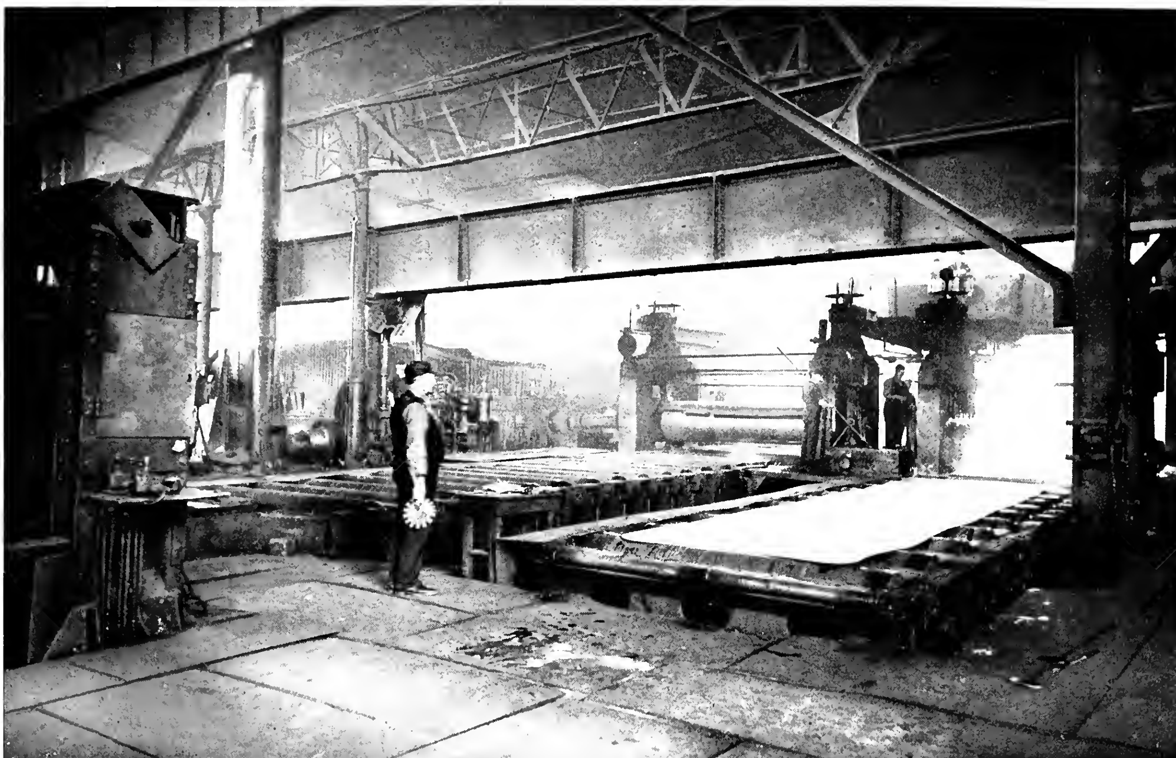


Photo supplied by David Colville & Sons, Ltd., Motherwell

STEEL PLATE ROLLING

triumph of human ingenuity, and the handling of the hot steel by the rollers looks for all the world as if the work was being done by a monster human hand.

Or, take again the making of steel wire. The big lump of metal comes to the rolling mills scorching hot: the first of the sets of rollers takes it in hand, drags it through until it appears doubled in length; then its end is put into the second set of rollers that again double its length, the whole being done at a lightning speed, the steel retaining its high temperature owing to the vast friction to which it is subjected. The men in this department need to have all their wits about them, for, as the iron wire elongates, it travels at a tremendous rate of speed, and the men at the end where it comes out must catch it at once and get it into the rollers again with no delay, or the work would be clogged, and the temperature of the steel would fall too low for the rollers to be able to cope with it. When the wire goes through for the last time, a little donkey engine deals with it. As the wire comes out like a furiously darting snake of fire, its end is delivered to the drum on the donkey engine, which at once clatters furiously and gathers up the slack, so that within a second or two of the ribbon of steel having left the roller, it is neatly coiled ready to be handed on to the next department.

To get an idea of the way in which steel is handled, you need yourself to go over a steel foundry, but it may help you to realise the enormous forces that have to be handled when I tell you that the governors of the powerful engines that drive the rolling mills, which can remain at a fairly acute angle while the rolling is in progress,

stretch out taut and rigid the moment the steel has escaped from the rolls.

Innumerable descriptions have been written of the grander steel operations, but, as all descriptions must do, they have, I think, failed to realise more than a tithe of the interest. I propose, therefore, to conclude this chapter in a rather different way from the usual, and to try to indicate to you the extraordinary complexity of the processes that have to be gone through to get so ordinary a steel article as a common file.

When the crude iron ore comes out of the earth, it has first to be taken where it is roughly freed from earthy matter and melted down into what are known as pigs. The pigs are taken to the steel foundry, where, by special processes, the carbon is taken out of the brittle steel and the file-maker is able to start with the raw material that he speaks of as billets. The great factor in steel production is to have exactly the requisite admixture of carbon, and to secure this the file-maker has to melt his steel afresh. For his crucible he uses china clay, and in a tool-maker's factory it is one man's duty to spend his whole life treading the soaking china clay, for if the very smallest air-bubble is left in the clay when the crucible is heated to the intense temperature required, the bubble swells and shatters the crucible. The crucible is placed in the furnace, and then if it withstands the heat, we come to that aspect of the process that forces out of us an admiration for the amazing adaptability of man. There is one man whose duty it is to lower into the crucible the mix, as it is called, that contains the steel in the exact proportions that are required for the making of the file. It sounds no great feat perhaps,

but when the time comes for him to have to remove the crucible from the furnace, he has to wrap his limbs in sacking and to walk knee-deep into water. Armed in this way as a protection from the heat, he removes again the top of the furnace, stands over its fiercely blazing depths, and with a pair of long tongs he removes the crucible with its white-hot metal from the furnace, where it has been smelting for three to four hours. There is nothing particular in that you may think, but you must remember that a single mistake, and the half-hundredweight of steel—no light weight, by the way, to lift—may be spoilt and lost, for the extraordinary thing about steel at this high temperature is that it can make its way where so subtle a substance as water would be unable to penetrate. But what of the man? In the short time it has taken him to lift out the crucible his soaking wet sacking has been dried to the state of tinder, and, indeed, as likely as not, is already smouldering. The crucible's load is delivered into a mould, and is cast as an ingot, and it is again a special man's duty to break off the ingot just that upper portion of the steel that contains air bubbles, for if once an air bubble gets past this stage, it will never again be eliminated from the steel. The ingot passes to the cogging mill, where it is cogged down to pieces of one and a half to two inches square. But our file, as we will now call it, has to go to the forger, who hammers it into shape and tapers the end, and forges on to it the tang that will eventually fit it to the handle. When the forger has done with it, he passes it on to the annealing furnace.

Annealing is a process that runs so thoroughly through engineering, that it is worth explaining. If a substance

is allowed to cool quickly, it is unable, as it contracts, to do so without it being left badly strained, and if we want to have a substance unstrained after it has been heated, it is necessary to allow it a very long time to cool—four to eight hours in the case of our file—in order that the whole process may go on with absolute uniformity. When our file has cooled for eight hours, and is soft, it goes to the grinding shop, where it is ground bright all over and prepared for the file-cutting machine. The method of cutting these notches is beautiful from its simplicity. The file is drawn under the point of the chisel-shod hammer, that is moving up and down against heavy springs so rapidly, that for the finer types of file it is impossible for the eye to see that any motion is taking place. Even for a 14-inch file, when there are nineteen teeth to the inch, the hammer strikes its blows at the rate of 450 blows to the minute. If you look at a file you will notice that the cuts run crossways, the cut first made being curiously enough known as the over cut, while the cut made second is known as the up cut.

The file is far from being finished yet, for, as you will remember, it was specially softened so that the chisel-shod hammer might do its work, and it now has to go to another department, where it is dipped in molten lead. Molten lead is used for this, as it gives the exact temperature wanted. The man in charge takes it from the lead and plunges it into brine, the sudden chill makes it contract unequally, and while it is still hot the man bends it straight again across two hickory bars that run across the brine tank, and so the process continues, chilling and bending, chilling and bending until a straight, hardened file is the result. The work requires a high order of skill and superb

judgment, for some of the fancy files now in use will whip into a sickle shape as soon as they start to take the chill, and it is only in the early stages while they are still hot that they can be bent back, for the file buys its hardness at the expense of being brittle. As the file was passing along the machine that cuts the teeth, the speed was so enormous that the chisel was never able to get out of the cut quite in time, and if we were to look at the teeth we should notice that they were all bent over a little at the top. This throwover, as it is called, has to be removed, and so the file passes to a place where it is subjected to a violent blast of steam and sand. This removes the throwover, sharpens the teeth, and gives to the file its beautiful grey finish. Then the scourer takes it in hand, and he scrubs it with oiled brushes, and so it comes to the file manager to stand its trial. Each file is "proved" independently. The manager has before him a lot of strips of steel so tempered that the file should be able to cut them. If, as the steel is carried across the file, a bright streak is left on the file, the prover knows that it is not up to standard hardness, and back it has to go to the works to be treated afresh. It is only when the file manager has passed it that it can be packed in a bundle with the rest and sent out to do its work in the world.

The story of the common file should give you a fair idea of the vast industries built up on steel, and the amazing amount of work that this steel industry gives to this country. If you feel doubtful of the truth of this, just cast your mind over the chapters of this book, and remember that every steel substance mentioned in it has had to go through a whole chain of similar processes. Or take a single

day in your life, considering it from beginning to end, and you will be astonished when you realise how intimately, both directly and indirectly, you are bound up with the manufacture of steel. Bearing this in mind, and remembering that iron and steel have to be smelted with coal, I will quote to you in conclusion a most suggestive passage from Professor John Perry's lecture on "Spinning Tops," and leave you to draw your own conclusions as to the other ways in which we are making use of our coal reserves:

"Imagine the following question set in a school examination paper of 2090 A.D.: 'Can you account for the crass ignorance of our forefathers in not being able to see from England what their friends were doing in Australia?' Or this: 'Messages are being received every minute from our friends on the planet Mars, and are now being answered: how do you account for our ancestors being utterly ignorant that these messages were occasionally sent to them?' Or this: 'What metal is as strong compared with steel as steel is compared with lead? And explain why the discovery of it was not made in Sheffield.'

"But there is one question that our descendants will never ask in accents of jocularity, for to their bitter sorrow every man, woman and child of them will know the answer, and that question is this: 'If our ancestors, in the matter of coal economy, were not quite as ignorant as a baby who takes a penny as equivalent for a half-crown, why did they waste our coal? Why did they destroy what never can be replaced?'

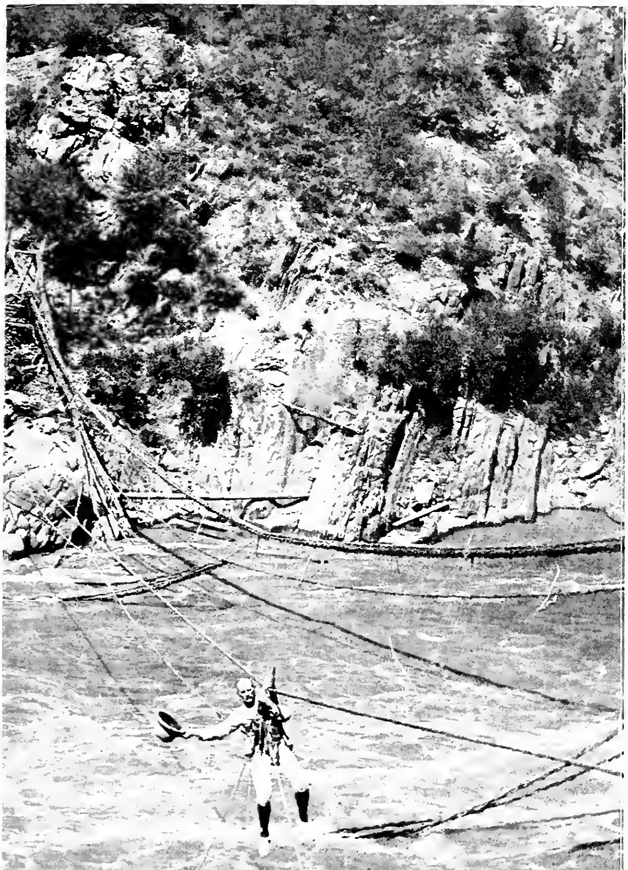
"We look on Nature now in an utterly different way, with a great deal more knowledge, with a great deal more

reverence, and with much less unreasoning superstitious fear. And what we are to the people of 3,000 years ago, so will be the people of 100 years hence to us; for indeed the acceleration of the rate of progress in science is itself accelerating. The army of scientific workers gets larger and larger every day, and it is my belief that every unit of the population will be a scientific worker before long. And so we are gradually making time and space yield to us and obey us. But just think of it! Of all the discoveries of the next 100 years; the things that are unknown to us, but which will be so well known to our descendants that they will sneer at us as utterly ignorant, because these things will seem to them such self-evident facts; I say, of all these things, if one of us to-morrow discovered one of them, he would be regarded as a great discoverer. And yet the children of 100 years hence will know it; it will be brought home to them, perhaps at every footfall, at the flapping of every coat-tail."

CHAPTER XV

BRIDGE-BUILDING—THE FORTH BRIDGE—THE TAY BRIDGE —THE BRIDGE ACROSS THE MENAI STRAITS—THE BROOKLYN BRIDGE—TRANSPORTER AND SWING BRIDGES—TRANSMARINE BRIDGES—A WONDERFUL FEAT

It depends, no doubt, on one's special point of view, what one considers as the most marvellous type of engineering work, but it would be an easy matter to make out a good case to show that the work of the bridge-builder takes precedence over that of most other types of engineering construction. The bridge, like the road, is with us, no matter where we go, and there are few of us who have not, even in our greenest childhood, had experience of floods and listened somewhat awestruck, but hoping for the best—which was what our elders would have regarded as the worst—that the forces of Nature would triumph over the ingenuity of man, and that the little bridge over our local stream would be swept away in the fury of the turbulent yellow waters. For then we should have been able to watch the actual construction of a bridge. There is one man and one man only who, as yet, has written the story of bridge-building, and that is Mr. Rudyard Kipling. The account appears under the title "The Bridge-Builders," in "The Day's Work," and if you have not read it, you should do so without delay, for by his amazing genius Mr. Kipling has realised in it the problems with which



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A BRIDGE OF ONE RAW HIDE ROPE AT URI, INDIA

This bridge is not used by tourists bound for the capital, but is only for local traffic. The rope of twisted raw hide is about an inch thick. A V-shaped yoke of wood is placed over this, with loops of rope extending from each of the arms of the yoke in which the traveller sets his legs as if they were stirrups. A light line attached to the yoke or saddle is being pulled this way so as to haul the passenger across. The ropes of braided twigs seen in the distance are the remains of an older bridge now out of repair

every bridge-builder from time immemorial has had to grapple. There are few engineering works where man is so forced into direct and personal conflict with Nature as he is when he tries to bridge one of the great gaps that Nature has placed as an obstacle in his path.

The art of bridge-building would require a whole encyclopædia to do it justice, and when the encyclopædia had been duly written and published, only a month or two would have elapsed when Nature would fling at us a new problem with fresh conditions to exercise the ingenuity of the engineer to try and overcome them.

To me the Forth Bridge is the bridge of all others, for, I remember, years ago, when the bridge was still a structure for the world to wonder at, how I walked out from Edinburgh to see it, having only just time to get to the top of the hill that gives you a glimpse of the structure, and then hurrying back across all the intervening miles to get into Edinburgh before dark. And the Forth Bridge still remains one of the great engineering feats of the world. I have before me now one of those curiously interesting books that are occasionally brought out on the completion of great engineering works, written by one of those who were concerned in its accomplishment, and lavishly illustrated with drawings, showing the work in the various stages through which it passed.* The bridge was built under the shadow of the catastrophe in which the Tay Bridge was wrecked. What was the problem to be solved? The Forth carried a vast quantity of shipping on its waters, and the free passage of this could not be impeded; it is over a mile wide at the point selected for the crossing, and

* "The Forth Bridge in its Various Stages of Construction, and Compared with the Most Notable Bridges of the World." By Philip Phillips.

some 1,760 feet from the north side there is an island with a deep channel on either side of it. The width of these channels was a third of a mile each, and so it was necessary that each of the main spans should be of this gigantic length. The advantages of a bridge across the Forth can easily be gathered from the statement that to travel from Edinburgh to Burntisland, two places about 8 miles distant apart, necessitated a railway journey of some 80 miles.

The building of the bridge was not accomplished without some hairbreadth escapes. Thus, there was an instance of a man trusting himself at a height of 100 feet above the water by grasping a single rope. The cold was such that his grasp slipped, and he fell headlong into the water, being fortunately picked up alive. On another occasion, a spanner fell a distance of upwards of 300 feet. In its passage it knocked off a man's cap, and fell on the stage at his feet, passing clean through a 4-inch plank. Many of the accidents occurred through carelessness. Thus, some of the boys engaged were seen jumping from plank to plank in the upper works, regardless of the sheer distance below them, and a case worthy of mention is that of two men whose intention it was to cover up a hole with planks. In carrying material for the purpose, one of them walked backwards into the very hole he was about to cover.

The Forth Bridge is built on the cantilever principle. It is enough for our purpose if we realise that by the cantilever principle is meant a type of construction where from a central portion the bridge springs out in both directions so that the weight on one side balances that on the other, and consequently the whole weight of the bridge

itself and any traffic it may be carrying is borne directly on the central support.

As the illustration shows you, there are three of these great cantilever systems in the Forth Bridge. The first essential, obviously, was to get a secure foundation for the piers that were to carry all this vast weight, and as the principle of building piers under water is more or less uniform, and as consequently the work has frequently to be performed by engineers, we may as well see how it is done. While divers are amazingly clever at their work, it is almost invariably necessary that an under-water foundation should be excavated in the dry, and the simplest way of effecting this is by making what engineers call a coffer-dam. In the case of the Forth Bridge, they did it where the water was fairly shallow by driving into the ground a great circle of heavy piles and putting clay between them. Large beams were stretched in all directions in the circle thus formed to prevent the pressure of the water breaking down the palisade. Then the pumps were got to work, and as the clay prevented the water forcing its way between the piles an area of land sufficiently dry to enable men securely to dig the foundations was laid bare. It was no light job digging down for the foundations of the Forth Bridge. They were sunk altogether a distance of 35 feet below high water, and then the engineers covered the bottom with a few feet of concrete, on which they constructed their masonry piers.

This part of the work the engineers regarded as relatively simple, and it was only what they spoke of as the pneumatic process that gave them any real anxiety. Some of the piers off the island in the middle and on the Queens-

ferry side had to be set up in comparatively deep water, and the piers in question are not the size that even a Samson could clasp in his arms. Each of them was 70 feet in diameter, and then tapered till at the top it was 49 feet across. In one of them special difficulties were encountered, but I think we shall see that the difficulties in the work of the ordinary piers were quite great enough for us to be content to say little about that.

In order to get dry land for excavation, caissons had to be used. The simplest way of getting an idea of what a caisson is, is to look on it as a great gasometer, but without the gasometer's weights and chains. These were built on the shore in cradles so that they could be launched into the sea just as a ship is launched. For the most part, they were made of wrought iron, but the bottom cutting edge, where, of course, the diameter had to be 70 feet, was of steel. Seven feet from the bottom of the caisson, there was a partition running right across the caisson, so that the lower portion could be made air-tight, and men could use it as a working chamber. On the top of the roof of this working chamber, the caisson had an inner as well as an outer skin, there being a space of about 7 feet between the two, and this space was divided into independent chambers, any one of which could be filled with concrete, so as to bring special weight to bear on any part of the cutting edge that happened to come against any specially hard substance. You have probably by now jumped to the right conclusion that the caissons were lowered into the river-bed, where the foundations were required, and served instead of coffer-dams. We will pass on now to see how those caissons were used.

If you had been present at the Forth on the 26th of May, 1884, you would have witnessed an interesting sight, and been in good company, too, for the Lord High Commissioner and the Countess of Aberdeen were there. Towering up above the ways stood one of those great caissons ready to be launched. An hydraulic ram set the mass into motion and it glided into the water as if it had been a ship, without a hitch. To complete the illusion, there were several people on board, and as soon as the launching had been completed, steel hawsers were attached to drag the unwieldy craft into position. And then it looked as if it were going to capsize, for suddenly it took a violent list, owing to the lower chamber being filled with air. Fortunately, however, the air got free by discharging itself under the lower edge and the caisson righted, having given its designers a very bad quarter of an hour, however, while it was doing so.

Now we must suppose the caisson is in position, and its top, you must remember, will always be above sea-level. A start is made to force it to the bottom by putting in heavy weights. The caissons used for the Forth Bridge each weighed 400 tons, and when they were completely loaded, weighed 15,000 tons. With the gradual increase in weight the caisson would sink until its lower cutting edge reached the bottom of the sea-bed. The lower chamber now would be partly full of water and air-pumps would be got to work, until the compressed air had driven the water completely out of the chamber, so that if we were to put ourselves in imagination at the top of one of the caissons we should find ourselves looking down on the interior of an enormous tub, and should know that the floor of the tub was at the same time the roof

of a great air space 70 feet in diameter and 7 feet deep. Suppose we wanted to go into this air chamber, we should clamber down the side of the caisson, a pretty long steep climb, and we should then be standing by one of the air locks. It is an easy matter for us to see what an air lock is in principle. We shall have in front of us a couple of stout iron doors opening inwards, and as we pass through into a little room and try the doors on the other side which will open outwards into the chamber below, we shall find that they are fast shut. Meanwhile our guide will have closed the doors through which we have come, we shall hear a hissing sound, for he has put our little room in connection with the air-pumps, and if we happen to have a barometer with us, we shall see that the mercury is running up to the top of the tube. Let us try those inner doors again, just as you may have seen the men at the dock gates trying to move the gates when they see that the level in the lock and the level outside are the same. They move quite easily now, because the air pressure in our room has been made the same as that in the space where the men are working. An air-lock, in fact, operates just on the same principle as a water-lock.

What a sight this space into which we have got is to look at!

There are brilliant lights hanging from the roof, hosts of workmen burrowing into the sea-bed, mechanical diggers tearing up their loads, trolleys taking the rock and stone away to the tubes by which the material will be dragged by cranes to the surface, and rock drills battering the rock face, and, if we could only see it, the great caisson itself slowly lowering its way deeper and

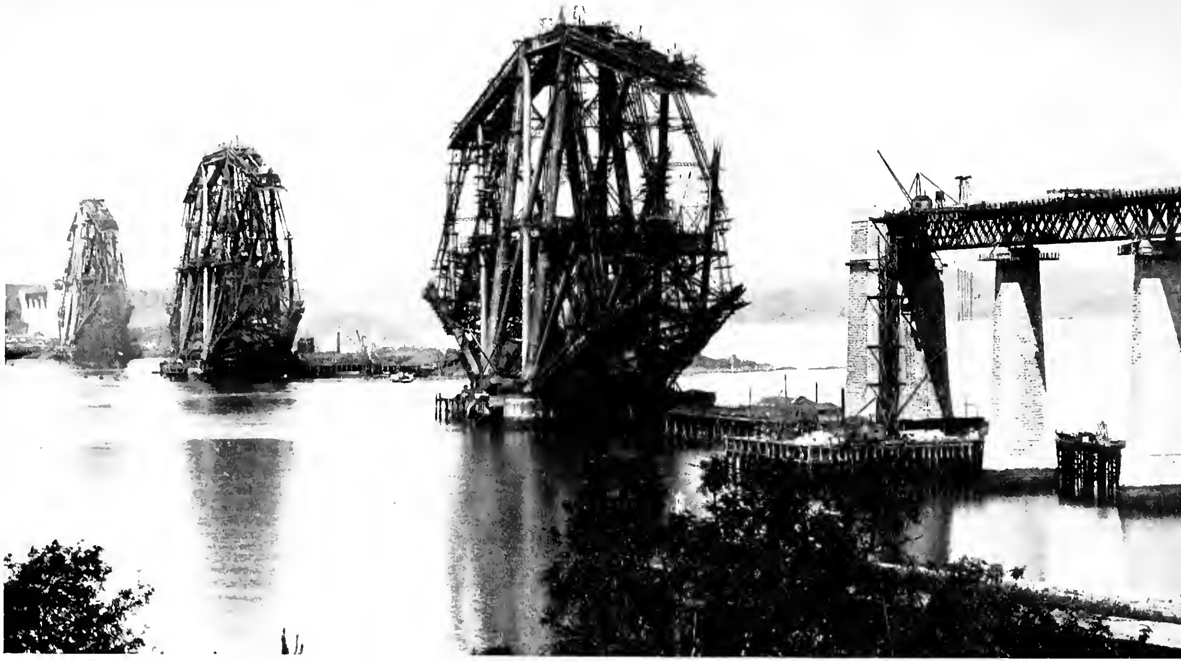


Photo: Fred W. Hardie, Aberdeen

THE FORTH BRIDGE IN COURSE OF CONSTRUCTION

deeper beneath the surface of the water. If we came back a few months later, when the excavation was finished, it would be a very different sight we should be looking at. There would be no need now for the air-lock, for the caisson would have long ago got firmly into its bed, and we should be looking at the masons constructing the great pile which is to carry one of the monster piers.

Most of the work connected with the caissons was carried out without a hitch, but in one instance an unlucky caisson did half-capsize after it got into place, and gave the engineers eleven months' hard work to get it back into position. One of the most novel incidents connected with the work occurred before one of the caissons had reached the sea-bed. Seeing the rays of light coming from beneath the cutting edge a diver started to explore, and suddenly walked beneath this edge, startling all those who were at work there; and a thing that always surprised those who visited the compressed-air chamber was that if they lighted a match, and blew it out, it always lighted itself again. They were also surprised at finding that in the compressed air they were unable to whistle.

As regards the construction of the bridge itself, it is necessary to remember that the great spans had to be built out all the time equally from side to side, so that the balance of the structure should be continually maintained. As you know, the bridge is built of great iron tubes. These reached the engineers just as they had left the rolling mills in the form of plates. Each plate had to be put in a gas furnace where its temperature was raised to a dull red heat. Hydraulic cranes lifted them to a giant press that could exert a pressure of 1,000 tons, and they

were then squeezed into shape, being pressed again when they were cold, as, despite all precautions, it was found that they altered a little in shape as they cooled. The amount of rivetting that had to be done was stupendous. It is estimated that the bridge ate up no fewer than 5,000,000 rivets, and for this, of course, 10,000,000 holes had to be drilled, for the conditions of the work made it unwise to punch the holes. Hydraulic power was used for pressing home the rivets, and by means of a pressure multiplier 3 tons to the square inch was brought to bear on the rivets.

If I attempted to deal with all the many ingenious contrivances employed in building the bridge, we should have to stray into many technicalities, and, moreover, we should have no room left to speak of other wonderful bridges, so I will content myself with quoting a few of the chief dimensions of the Forth Bridge:—

Total length	over $1\frac{1}{2}$ miles
Cantilever arms	680 feet
Central girder	350 ,,
Depth over piers	342 ,,
Diameter of largest tubes ..	12 ,,
Total amount of steel in bridge	over 50,000 tons
Wind pressure allowed for ..	56 lbs. per square foot
Dead weight on a single circular pier	16,000 tons
Miles of steel plate used for tubes	over 40 miles
Total contraction and expansion allowed for changes of temperature	6–7 feet
Largest number of men employed at one time	Between 4,000 and 5,000

For many long years the Tay Bridge will be associated in our memories with a terrible disaster, a disaster that had a great deal to do with the form ultimately decided on for the Forth Bridge. The difficulties in its construction depended more on the magnitude of the work than upon the application of any new principles, though the rapid flow of the waters of the Tay at times caused the engineers considerable anxiety. The cost of the bridge was £130,000, and though royal assent was given to the Bill promoting it in July, 1870, it was not until September, 1877, that the first train was driven across it. The length of the bridge was 10,350 feet, and it included in all 85 spans, supported by the same number of piers, some of which were of brick, but the bulk of cast-iron cylinders with wrought-iron struts and cross bracing between.

It was on the night of the 28th of December, 1879, about eighteen months after the public opening, that a terrible storm raged over the north of Scotland. The northern express had been duly signalled into Dundee Station, but did not make its appearance. No one thought much of that, but a journalist, who happened to be passing in the streets, was accosted by a drunken roysterer, who was talking incoherently about having seen a blaze of fireworks on the bridge, and who thought the bridge had broken down. It did not strike him as anything very peculiar, though it seems that he was the only human being who witnessed the catastrophe, but the journalist, horrorstruck, went to the station to make inquiries. At the station there was no anxiety, but to re-assure him, the authorities telegraphed to the signal-box across the bridge. To the signals they sent out there was no reply, and it

was not long before the awful truth was known that the train with its load of ninety passengers had plunged into the gap of the bridge to its doom. It was through that one journalist that the news of the catastrophe was made known to the world. There was a solitary survivor, a small dog that floated ashore from the wreckage, and a friend has told me that he remembers reading a paragraph in the papers years later when the dog died, recalling that it was the only living creature that was saved from the wreck.

An investigation was made by the Board of Trade into the cause of the disaster, and the opinion given was that the vertical columns of the bridge had not been sufficiently braced to withstand the lateral wind pressure. By the side of the old bridge, a new one was eventually constructed—the bridge that is in use at the present day. In the new bridge, advantage was taken in an ingenious way of the lifting power of the tides. When the piers had been completed, and it became necessary to bring out to them the girders that had been built on shore, two monster pontoons were floated at low water under the ends of the girder in question. As the tide rose, the pontoons took the weight of the girder, and were towed out to the pier. The pontoons were then moored so as to be directly under the position that the girders were to occupy, and when high water had been reached, packing was put under the girder to keep it in place, and the pontoons dropped away with the tide. At low water, again, the girder was packed securely on to the pontoons, and the tide again lifted it by the whole of its rise, and so the process went on until the girder had eventually been raised to the necessary height.

Photo: Underwood & Underwood, New York

BRIDGE BUILDING

Workmen placing into position one of the immense uprights 200 feet above the river

I have beside me, as I am writing, the original account of the Menai Bridge, that was prepared by William Provis, who was acting engineer for Thomas Telford, the engineer responsible for the work. It is a curious unwieldy volume published in 1828, and is 2 feet 3 inches tall and over $1\frac{1}{2}$ feet across. In his preface, Provis writes with reason :

" Few works connected with the profession of a civil engineer have excited so strong and general an interest as the Suspension Bridge over the Menai Strait, between Anglesea and Carnarvon ; for though the principle of its construction is as old as the spider's web, the application on a scale of such magnitude, the durability of the materials of which the bridge is composed, and the scientific combination of its various parts, render it one of the noblest examples of British skill. As a public convenience, too, it is of the highest importance ; for instead of an uncertain ferry over an often tempestuous Strait, at all times crossed with trouble and delay, and frequently at the risk of life, a commodious roadway has now been established between its shores, that can be passed at all times with safety and comfort."

As you probably know, the essential feature of a suspension bridge is that the roadway is slung on wires that pass from lofty towers that are built on the shore ends, the chief advantages being that in this way navigation is not impeded by piers being sunk throughout the fairway, and that the bridge itself can easily be slung high above the stream without there being any danger of interfering with shipping. Provis gives a very full account of the way in which many of the local pilots hotly argued that the

bridge would make the navigation of vessels under it a proceeding of great danger, and it is curious to find from time to time a reflection in his account of this engineering work of the vanity of man. Thus he writes:

"Accordingly, on the 10th of August, 1818, the first stone was laid. Two of the Commissioners, viz. Sir Thomas Mostyn and Sir Henry Parnell, were in the neighbourhood, but as it had been previously determined that it should be attended with no public ceremony, the worthy baronets declined giving their attendance. It was, accordingly, lowered to its place and set, by myself and the masonry contractors, whilst three cheers from the surrounding workmen closed the ceremonial."

Many difficulties were encountered during the work of building. On more than one occasion, the vessels used in connection with the work were shipwrecked, so much so that the masons were frequently held up for want of stone. A special machine had to be constructed to test the ironwork used, as Telford insisted that each bar should pass a test twice as severe as that to which it would be subjected in the bridge. To facilitate the work of repair the method of building was such that any portion could be taken out and replaced independently. So important was it that the iron of the bridge should fit perfectly on to the stone that, though the masonry had been dressed as smooth as masons' tools could make it, yet as neither its surface nor those of the iron castings were so smooth as to produce a perfect contact, they had recourse to the curious expedient of saturating two or three thicknesses of coarse flannel with white lead and oil, whereby a perfect fit was secured. Again, when the second set of the giant

chains that were to carry the bridge had been put up, it was found that some of the links had been damaged, and the ingenious method was adopted of taking the strain off one of the damaged links after another, and replacing them without having in any way to disturb the position of the chain. The total weight of the bridge suspended was, according to Provis's calculations, 643 tons 15 cwts. 2 qrs. 7 lbs. The distance between the supporting pyramids of the bridge was 560 feet. The pyramids themselves were 50 feet above the roadway, and the sixteen chains which passed over the pyramids were securely anchored in masses of masonry. As you will see, there are in the Suspension bridge four essential factors: the piers that carry the downward pressure, the pyramids on top of which the chains ride, the chains themselves on which the bridge is slung, and the heavy masonry by which the chains are firmly anchored to earth.

Since the great bridge across the Menai Strait was built, there have been huge suspension bridges erected all over the world. There is the Conway Suspension Bridge, for instance, constructed by Telford, the Clifton Suspension Bridge thrown across the Avon in the midst of wild picturesque scenery, and that made use of the massive chains that had been a part of the Hungerford Bridge at Charing Cross, but the most noted example of this type of construction is the bridge known as the Brooklyn Bridge, that connects Brooklyn and New York.

The bridge spans the river that separates these two centres, and as this is crowded with shipping, it was obvious from the outset that a lofty structure was essential, so that the vessels should not be interfered with. Figures will

demonstrate that it was no light task that had to be achieved. The distance was 5,889 feet, or considerably over a mile. The towers were 276 feet high, and placed 1,600 feet apart, and the original estimate of £2,160,000 for the cost grew to £3,100,000, because the Government insisted that the bridge should be 5 feet higher and 5 feet broader than was originally intended. The weight of masonry to which the four cables supporting the bridge are anchored weigh 60,000 tons apiece.

The engineers began by building the towers in 1870. On the Brooklyn side, the work took five years, and on the New York side, six, for the foundations had to be carried 79 feet down below the high tide level deep into solid rock.

The most dramatic feature of the work was the first spanning of the gap between the towers. A huge steel rope was coiled up on the Brooklyn side of the river, and the end dragged up to the top of the Brooklyn tower, and let down from this into the river below. Then a tug took charge, and dragged it across to the New York side, where it was drawn round a drum at the top of the New York tower, and sent back to Brooklyn. In this way, the engineers had an endless rope along which men and material could be drawn from end to end. The first man to cross from side to side by the bridge was Farrington, one of the engineers. The journey took 20 minutes to make, and all that those below could see was the man swaying in the wind as the wires bent beneath his weight. With the towers completed, and union between them effected, the work went rapidly. It was decided that the bridge should be slung on iron skeins. The threads form-

Photo : Underwood & Underwood, New York

BRIDGE BUILDING

Putting a cross beam into place

ing the skein were only $\frac{1}{8}$ inch in diameter, and each skein consisted of some 300 separate threads, and to make the skein, the wire had to be carried backwards and forwards with the traveller that had been set up. Nineteen skeins went to a cable, and elaborate precautions had to be adopted when the time came for them to be tied together to form the united whole. It was the essence of the work that each wire should bear its fair share of the weight, but when the sun shone on the bridge, the wires expanded and contracted unequally; when the wind blew, there was a similar result, and it was, therefore, only on calm, sunless days that the tying of the wires could be effected.

In the course of the work, there was one occasion when a disaster was only narrowly averted, and that by pure good luck. The skeins of wire were, of course, subjected to an intense strain, and once one of these became unmoored from the New York side. The effect was as if the god Vulcan had suddenly turned Cossack, and was cracking a whip of steel over the waterways of the city. The released skein tore to the top of the tower, and hurtled all amongst the shipping below, by a miracle of good fortune avoiding all the craft.

In the completed bridge, elaborate means have been adopted to allow for expansion and contraction. The cast-iron saddles on which the cables rest move over forty iron rollers, and the bridge itself is in two sections, joined in the middle by a sliding joint; the effect of contraction and expansion is seen by the fact that the bridge rises above its normal height in the winter months, while in the hot days of the New York summer it sags below it.

Here are a few of the dimensions of this remarkable bridge:

Headway	135 feet
Size of New York caisson ..	172 feet by 102 feet
Greatest width of bridge ..	85 feet
Cubic contents of New York tower	47,000 cubic yards
Diameter of cables	$15\frac{3}{4}$ inches
Total length of single cable ..	3,600 feet
Length of wrapping wire in each cable over	243 miles
Sustaining power of each cable	12,000 tons
Weight of each cable	3,000 ,,
Length of wire in each cable ..	3,500 miles

At Niagara, it may be of interest to note there are both suspension and cantilever bridges.

The bridge that the engineers have thrown across the Zambesi River, just below the Victoria Falls, has attracted world-wide attention. The Falls themselves are one of the marvels of Nature, for in the distant recesses of time an earthquake shattered the river bed, opening a crack 100 yards wide, and making the river fling itself down into a gulf 400 feet deep. The noise of the Falls is like that of incessant thunder, and the natives of Africa speak of them with bated breath as the "Place of the Sounding Smoke."

The principle on which the bridge has been constructed is that of the simple arch that we have had handed down from a time that outstrips the memory of man, but the material used was of iron girders, and you can imagine that it was no easy task for the engineers to arrange for all their material to be built in this country, and to have it shipped across, carried to the Falls by the Rhodesian Railway Company, and then set up by native labour.

In the Brooklyn Bridge, you will remember one of the first things was to span the gap between the towers. At the Falls, the engineers had the same problem, and they solved it ingeniously. A powerful sky-rocket threw a light line from the one bank to the other. To the line a stout cord was attached, and then a rope, the rope being followed by a wire cable 2 inches thick. On this wire a cage was suspended driven by electricity, and from this cage, suspended at the dizzy height above the river beneath, the men did the bulk of their work.

It is, as you know, the essence of the arch that the keystone enables the structure to hold firmly together, and it is easy to realise, therefore, that as the bridge was being built out from side to side, it was necessary to provide strong supports to carry the overhanging weight of the girders. An ingenious method was adopted for carrying this weight. On each bank a couple of holes were drilled into the rock, 30 feet apart and 30 feet up, their bases being connected with a small tunnel that ran under the living rock. Through this a stout wire rope was passed, and the ends of it were carried out to the overhanging girders of the bridge. So great was the strain placed on the wire and the solid anchorage of rock, that, to prevent all chance of the wire tearing out of the anchorage, the ground between the holes was weighted with 5,000 tons of railway rails.

And now we come to what is, I think, the most dramatic instance I know of the part that expansion and contraction through changes of temperature plays in engineering work. The bridge was finished all but the central girder, the keystone of the arch. The girder was slung into place,

and it was found to be $1\frac{1}{4}$ inches too long. Meanwhile, the sun was blazing down on the engineers, and with the girder ready to slip into position they waited for the cool of the night. As the sun dropped to the horizon, the great girder began to contract, and by the time that it had cooled through the night, it, and the bridge with it, had contracted so that it fitted perfectly, and was securely bolted home.

For all that we regard the Tower Bridge as something entirely novel in design, it is, as a matter of fact one of the oldest types of bridge construction in the world. The engineers then were faced with the same problem they had had to deal with in the Forth and Tay Bridges, in the Brooklyn Bridge and in the bridge across the Menai Straits: to bridge over an expanse of water without interfering with the passage of shipping beneath it. The solution found in the Tower Bridge was, in essence, the same that was found by the knights of the Middle Ages with the swing bridges that gave admission to their castles.

Technically, the bridge is said to have been constructed on the "Bascule" principle; it consists essentially of two large piers, 200 feet apart, which carry between them two separate roadways. The one is a permanent structure for the use of pedestrians, and is 135 feet or more above the level of the water. The lower bridge consists of two leaves that are counterbalanced with extraordinary accuracy by heavy weights, so that the chief work that has to be done when a high-masted vessel wishes to pass below the bridge is to overcome any force that wind pressure may exert to prevent opening, and the relatively small amount of resistance offered by friction. The foundations of each pier were laid on twelve caissons, which were so formed as to

make a coffer-dam. Inside this a solid bedding of concrete was put down, and this was carried almost to the surface of the river-bed, above which granite was used. In these piers, as in the towers that are carried on them, the lifts and the hydraulic machinery necessary to operate the leaves of the bridge is contained. The size of each movable leaf is 100 feet long by 50 feet wide, and the weight 700 tons. Enormous masses of material were required for the work. There are 31,000,000 bricks, 70,500 cubic yards of concrete, 19,500 tons of cement, 235,000 cubic feet of granite and other stone, and 10,500 tons of iron and steel incorporated in the structure.

Another ingenious method by which the same problem of keeping open a waterway is solved is by a swing bridge, supported in the centre on a strong pier. You can see examples of the bridge in all sizes on the Norfolk Broads. There is a large one, for instance, near Yarmouth, that I have several times passed through, and very annoying it is, when you are sailing, to have to wait until the bridge is opened for you, and perhaps even more than with most bridges you almost invariably get a false wind as you are on the way through, so that you have to be specially careful that your boat does not come violently into collision with the sides of the bridge. There is one of these bridges on the Hull and Doncaster Railway, that is 250 feet long, and carries two lines of permanent track.

One of the prettiest and most modern ways—also curiously enough one of the oldest on a small scale—by which this same difficulty is met, is by what is known as the transporter bridge. In this there are, as usual, two lofty towers with a bridge running between them at a

big height above the river, the problem being by means of this high structure to give a passage to man, animals and carriages from one low-lying bank to another. It may be of interest to compare the problem with that facing the engineers at Clifton. There the river runs in a deep chasm, and the traffic already is far above the water-level, but the river bank is, in most cases, only a little above water level, and the cost of constructing a vast embankment up which loads could be drawn to the high levels of the towers would be prohibitive.

We will take the Runcorn Transporter Bridge as a type. It crosses the River Mersey and the Manchester Ship Canal between Widnes and Runcorn, and stands on four great iron towers, which on the Widnes side spring straight out of the solid rock, but on the Runcorn side are built on cylinders that had to be sunk 35 feet to get down to rock foundations. The bridge span, as you will see from the illustration, is supported by two great cables that ride over the summit of the towers, and the lowest girder of the 1,000 feet span is 82 feet above the level of the water. Rails are carried on this span and a trolley, electrically driven, runs from end to end, while slung beneath it is the transporter car, a stoutly-built structure, 55 feet long and 24 feet wide, that is capable of dealing with the heaviest loads of machinery that are brought across on it. It will give you some idea of the size of the transporter car when you know that 500 or 600 people are often carried across at a single journey.

Another instance of the ingenuity of the engineer in meeting the difficulty of navigation is what is known as the lift-bridge. The central span of these bridges is so

Photo: W. H. Mack, Runcorn

RUNCORN TRANSPORTER BRIDGE

arranged that machinery lifts it bodily from the low level at which traffic crosses it to a high level sufficient to enable big ships to pass beneath it. This type of bridge was set up at Halsted Street, in Chicago, and, owing to bad design of the machinery, was the standing joke of the town, because it almost invariably stuck at the critical moment. When a better type of machinery was installed, however, it worked perfectly, and the success of it, in Chicago, caused the adoption of the principle for the Kansas City Bridge over the Mississippi River. The bridge, when completed, was 4,150 feet long, and the central lifting span 425½ feet across. It carries a lower deck for railroad traffic and an upper deck 72 feet for cars and road traffic. When the span is raised to its maximum height above low water, there is a sheer drop of 100 feet.

Bridge-building is full of sensational feats, but the construction of a special railway across the sea so as to connect New York by railway carriage with Havana is, I think, quite without parallel. The railway line runs a distance of 156 miles from Miami on the mainland to Key West, 100 miles of which is over water, and the train then goes direct by train ferry the 90 miles to Havana. In its passage from Miami to Key West, the railway uses no fewer than forty-eight coral islands, called keys, as stepping-stones, and the water channels it crosses in between these islands are often several miles across with depths varying between a few feet to over 80 feet. The prospecting of this great bridge involved terrible hardships. The engineering parties often got lost, and they had to struggle in dense, alligator-haunted jungle. One episode in the work was when the contractors came across an island

lake with a bottom of soft peat. They tried to bridge it and failed, and they found it necessary to drain and fill it in, a work that cost them fifteen months. When the actual work of building the line across the ocean started, they found it necessary to use a most extraordinary fleet of boats—floating machine shops, barges, work boats fitted with concrete mixers and derricks, floating pile drivers, tugs, paddleboats, petrol launches and house-boats. When the islands were close together, embankments were built, and the line run along them. Larger openings were bridged with viaducts, one of which, 10,500 feet long, has 186 arches. Sometimes the engineers built their bridges of reinforced concrete, and at other times they used steel, but even then the foundations for the bridge had to be built on concrete piers. An extraordinary fact brought to light by the building of this railway was that on some of these islands there were men living solitary desolate lives, an individual Spaniard being found who said that he had lived on one of the islands for thirty years, making his livelihood from the natural resources of the island. The expense of construction was naturally enormous, working out to over £3,000,000, or at an average of £20,000 a mile. Its effect has been to bring New York into close touch with Cuba, and also nearer to Panama and the States of Southern America.

The subject of bridge building is almost interminable, and I will do no more than mention an amazingly bold scheme that they are thinking of adopting at San Francisco to cross the bay. The idea is to build a nine-mile bridge right across the harbour to deal with the heavy flow of traffic—passenger and goods—that at present has to cross day by day in ferry boats.

For the conclusion of my chapter I am indebted to the Editor of *Technical World Magazine* for leave to include an account of one of the most marvellous engineering feats in bridge building that it has ever been my lot to read about. As the author, Mr. Carlyle Ellis, puts it, there is an entry in the pocket-book of Mr. C. E. Hawkins, the engineer who built the Copper River and North-Western Railway in Alaska, under the date of May 14, 1910, which reads: "The false work under the third span of the bridge was moved out 15 inches by the ice, and had to be put back."

The bridge in question was the Miles Glacier Bridge across the Copper River and the third span was 450 feet long. The false work referred to was the mass of wood staging on which the third span rested before it had been made fast, and consisted of a thousand or two piles driven deep into the bottom of the Copper River, 40 feet below the surface. It was frozen solid with 7 feet of ice, and a 12-knot current raced underneath. The spring break-up had begun, and the ice-cap, lifted 20 feet above its winter level, was moving. The safety of the third span of the bridge was threatened with immediate disaster, for nothing could withstand the 7 feet of ice, if, gripping the piles, it started to try and lift them. Every available engine was put to furnishing steam to small feed-pipes, and every man in camp was set to work to chop or to melt the 7 feet of ice clear of the piles. And the work was done. The holes were kept open through days and nights of bitter cold, and hundreds of cross-pieces that kept the piles together had to be unbolted and shifted while the river rose 21 feet. It was noticed, however, that the false work was moving

down stream. It started by about an inch a day, then 3 or 4 inches, and at last the ice made its heaviest charge; a line was taken; the false work was 15 inches out, and it had to be put back. This meant fresh work for the men, who were already broken with cold and overwork, and a fresh load of anxiety for the over-burdened engineer. The ice-chopping and ice-melting had still to be done, but with diminished forces, and a gang of men was drafted off to build heavy anchorages into the ice up stream, to rig up blocks and tackles, and start dragging the massive false work back into place. Every day the ice was moving more freely, and there was less and less respite in the furious race the engineers were running with the river and moving ice. The last bolt of the span was sent home one midnight after an eighteen-hour day of one shift. The great steam traveller was slid to a temporary resting-place on the third pier, the blocks were knocked away, and the third span settled safe on its concrete bed. At one o'clock the whole 450 feet of false work was a tangled wreck, the piles twisted and torn and shattered. The river had won its fight, but an hour too late. The engineers had saved a year's work, and in that year a fortune.

The bridge that was saved in this dramatic way was the point on which the failure or success of the whole line turned, and the difficulties presented in its construction were unprecedented. Where the bridge crosses the river, it has to withstand the bombardment of giant bergs, hurled hour after hour against it at 12 miles an hour, and the piers have to be strong enough to stand the enormous pressure exerted by the break-up of the 7-foot ice-sheet spring after spring. The building of the bridge was a

$1,000,000 gamble, and if the engineers lost their stake, the loss carried with it disaster to the whole $15,000,000 project of the railway.

They started by driving great concrete piers heavily reinforced with steel through the winter ice, then 40 or 50 feet through the river bottom, till they came to bedrock, and they supported their piers by having a row of eighty-pound rails round them, all the piers being protected with ice breakers. This was not too easy a job, because before the work was over a lake burst out from the Upper Glacier, and raised the height of the river by 20 feet in an hour. But the unfinished bridge stood this test that was sprung upon the engineer without his having any warning.

At last the piers were finished by autumn, 1909, and the steelwork began to arrive. It was not until late in the spring of 1910 that the last numbered piece was on the ground, the whole checked and re-checked to ensure that there was not a single omission, which might delay the whole work a twelvemonth. Here is how Mr. Carlyle Ellis summarises the achievement:

"The checking of the steel was completed on April 5, which left less than six weeks to put together more than 1,100 feet of extra heavy bridge with a single crew of steel workers. Facing such a task, and with the prospect of raging storms of rain, sleet and snow about half the time, almost anyone but Hawkins, and his bridge engineer, A. C. O'Neil, would have thrown up his hands in hopeless despair. Within an hour of the time the last piece was checked the first big girder was in place. Ten and a half days later, the first span, 400 feet long, was completed.

Nearly 40 feet of towering steel structures a day with a single shift of men, day after day, through the storms and the darkness! But the second and third spans were faster still. The second, of 300 feet, was built in six days, and the giant third, of 450 feet, in spite of extraordinary difficulties, in an even ten days. The bridge was completed on May 16, except a fourth span, which was over shallow water above the danger of ice. The 1,150 feet of bridge was thus built in an elapsed time of just under six weeks, and an actual working time on the steel of twenty-seven days."

The feat, I think you will agree, amply justifies the statement that the exploit was unexampled in bridge building, and I will bring this chapter to a close by quoting to you from the account Mr. Hawkins himself gave of it. "The men," he said, "were on the job at seven in the morning, no matter what the weather. They worked without ceasing till the noon whistle blew, then raced each other to the mess tent. A few minutes later they were flying back like an army of squirrels, and there they stayed until eleven or twelve at night, or until flesh and blood could stand no more. It was the most amazing exhibition of loyalty, efficiency and endurance I have ever known."

CHAPTER XVI

THE GYROSTAT—ITS THEORY AND ITS APPLICATION TO VARIOUS INVENTIONS

PROGRESS throughout the world is in most instances conditioned by the discovery of a new instrument. Imagine, if you can, the stupendous effect on the world's advance of the invention of the wheel, the wedge and the screw. Let your mind now wander through historical time and notice how our control over Nature has been dominated by the discovery of the rail, the steam engine, the electric motor, the telegraph instrument, the telescope, the microscope, the turbine, and the other epoch-making inventions. In science each new instrument has usually, if not invariably, meant a fresh method of attack against the dark clouds of ignorance and stupidity; and as with science, so it is with engineering. The engineer is quick to seize on a new idea, and to find that by its help it is possible for him to perform operations that were previously beyond his scope. I do not wish to labour this point, which, after all, is clear enough in itself after a moment's reflection, but I propose to devote this chapter to a short consideration of the latest new principle that has been brought under contribution—the gyrostat.

What a curious irony it is, when you come to think of it, that the children of untold generations have been using in their play with pegtops just the same principles

as those on which the gyrostat depends, and that it has needed all these centuries before the right man came along to ask himself the question why the spinning-top behaved in its own peculiar manner. When you come to think of it, it requires explanation that the hoop will keep upright while it is being trundled along, and that the pegtop will "sleep" when properly spun—nay, it will do more, and resist any attempt to push it on one side from its upright posture—and that the bicyclist finds it difficult to balance himself unless he keeps moving at a certain speed. And yet most of us have handled these things, and not given a thought to the principles that underlay their action.

It is many years now since Professor John Perry, who is at present the Treasurer of the British Association, in delivering a special popular lecture, took the spinning-top for his subject. Before describing a few of the applications of the instrument I propose to attempt to give you some account of the principles of the instrument itself, as they were laid down by the late Lord Kelvin.

The gyrostat in essence is nothing more nor less than a flywheel spinning rapidly about its axis. Let me take an example of gyrostatic action that must be familiar to everybody. When you have taken down a bicycle and are thinking of putting the front wheel back into place, you have probably held it by its axle, and allowed the wheel to spin to see that you have not screwed the cones too tightly into the ball-race. In holding the wheel, you must accidentally, at any rate, have moved the axis with the wheel still spinning, so that you were attempting to turn it in a direction different from that of its former axis, and

you must have felt that the wheel resisted your efforts, acting as if it were a body endowed with life. Now that is a good instance of gyrostatic action, and tells us an essential of the spinning gyrostat, that it resists strongly any attempt to change its axis of rotation, or, put more technically, that the effect of attempting to rotate the wheel about a new axis is to send its spinning axis towards the direction of the new axis.

If we were to try to go farther than this into the laws governing the behaviour of a gyrostat, we should soon find ourselves landed in what most of you would regard as a mathematical treatise; so, instead, I will simply refer those of you who wish to go more deeply into the theory to Professor Perry's book on "Spinning Tops," and at the same time draw your attention to the rigidity that can be assumed by rapidly rotating bodies. Most of you will have heard that it is possible to cut through iron by means of a spinning disc of paper; if a jet of water is being squirted out with sufficient force, it is impossible even for a strong man to drive a sledge-hammer through it; a chain wheel spun on a mandrel, and slipped off it while it is whirling, will bounce from a table on to which it falls like a boy's hoop; and, to quote Professor Perry's own words for one of his illustrations, "Here is a very soft hat, specially made for this sort of experiment. You will note that it collapses to the table in a shapeless mass when I lay it down, and seems quite impossible of resisting forces which tend to alter its shape. In fact, there is almost a complete absence of rigidity; but when this is spun on the end of a stick, first note how it has taken a very easily defined shape; secondly, note how it runs along the table

as if it were made of steel; thirdly, note how all at once it collapses again into a shapeless mass of soft material when its rapid motion has ceased. Even so you will see that when a drunken man is not leaning against a wall or lamp-post, he feels that his only chance of escape from ignominious collapse is to get up a decent rate of speed, to obtain a quasi-sobriety of demeanour by rapidity of motion."

Now that we have some sort of idea of what a gyrostat is, we must realise that electricity is harnessed to it to give it an enormous speed of rotation, that the wheel will be enclosed in a vacuum to prevent the retardation due to the friction of the air, and that its weight will reach such dimensions as to be measured in tons.

At the Royal Institution recently, Dr. James G. Gray gave a beautiful demonstration of several of the curious ways in which a gyrostat will behave. For instance, if you have your top spinning on a horizontal axis and press down on one end of the axes, the axis does not tend to go off the level, but it starts to turn so that the part you are touching moves away crabwise. If the gyrostat is hung on gimbals so that it can swing like a ship's compass in any direction, you can turn the pedestal on which it stands just as you please, and its axis will remain always pointing like a compass in the one direction. This amazing instrument can be made to support itself on a skate edge, to ride a bicycle, correcting the balance automatically in the same way that a bicycle rider corrects balance, to keep itself upright when resting on gimbals, and to trace curious figures when fitted as the bob of a pendulum.

What, you may fairly ask me, has all this to do with engineering? I should be justified in including the gyrostat

in this book even if I had no better answer than to point to the fact that nearly every machine has some heavy wheel or other in a state of rapid rotation, and that in many of these, as on board ship, on motor-cars, trains and elsewhere, the axis of rotation is continually liable to change. Here is a force, therefore, that the engineer has to take very seriously into account, for the gyrostatic action of such parts will put a very serious strain on the machinery he has installed. But the gyrostat has entered still more directly into the work of the engineer. It is through it that Mr. Brennan has been able to construct his mono-rail railway, for he arranged his rapidly-whirling heavy turbines in such a way that they resist any attempt made to shift their axes out of the vertical, and force the train to keep a level position on the single line of railway on which they run.* Take again the application of the gyrostat to the torpedo. The working out of the way in which the torpedo could be guided by means of gyrostats so impressed the British Government, that they willingly gave Mr. Brennan £110,000 for the patent rights.

War is a great quickener of man's inventive powers, and the next most important application of the gyrostat is to provide men-of-war with non-magnetic compasses—with compasses, that is, that will not be affected by the firing of heavy guns, or by the massive steel with which they are surrounded. In this the gyrostat is mounted with its axis horizontal. In these circumstances the axis of the gyrostat lies in the plane containing the axis of the earth and the position occupied by the gyrostat; thus the equilibrium position of the flywheel is that in which its

* For an account of the mono-rail and the principle on which it works, see Mr. F. S. Hartnell's "All About Railways." (Cassell & Co.)

axis points to north or south. Another instance of the uses for which the gyrostat has been employed is to give additional stability to ships at sea. It is a matter of common knowledge that the cause of a ship's excessive rolling is the cumulative action of the waves, and that this is only possible when the period of a ship's roll and that of the waves are nearly the same. The effect of adding the gyrostat is to lengthen the period of roll, and thereby to put a small ship in the same advantageous position in this respect as that enjoyed by a large vessel. Also a method of using the gyrostat has been designed so that the energy of a ship's oscillations can be damped and converted into heat and dissipated at the bearings of the gyrostat.

You will remember that I have spoken of the gyrostatic action of the rotating parts of a ship and of a motor-car. Now a study of gyrostatic action teaches us that the action of the paddle-wheels results to a certain extent in changes in the direction of the ship's head taking the place of rolling, in such a way that if the steamer tends to tilt to starboard, her bow turns to starboard, whereas if she tilts to port, she turns to port. But it so happens that this tendency is corrected, for in tilting to starboard, for instance, her starboard paddles are more deeply immersed, and thus direct her head to port. Otherwise it would be a most difficult matter to steer a vessel straight in a heavy sea.

I cannot pretend that this chapter makes easy reading, but it is, I am afraid, an impossible task to treat of the gyrostat shortly and non-technically. There are so many ideas connected with it that require a more or less technical study of mechanics, that if I had aimed at giving anything approaching to a full description, I should have had to

deal in some detail with the elements of mechanics. These, if you are interested in engineering, you will before long have picked up for yourselves, and be able, by reference to the original authorities, to get a clear understanding of all the not very complex principles that account for the behaviour of the gyrostat. I shall have done sufficient here in drawing your attention to a few of the effects of gyrostatic action, and, I hope, in inspiring you to take a greater interest than you have done before in the toy that you have probably often seen sold under the title of the gyroscope top.

CHAPTER XVII

CABLE LAYING—THE STORY OF THE FIRST ATLANTIC CABLE —STRANGE EVENTS CONNECTED WITH THE DISCOVERY OF PALMYRA

No branch of engineering has done more to promote peace between the different nations of the world than the romantic one of cable laying. When the only means of intercommunication between the Old World and the New was by the sea, neither world knew much of the internal affairs of the other. In the imperfect state of knowledge there was abundant room for misunderstanding, and for the growth of bad feeling based on this ignorance. Commercial dealings, the strongest of all possible forces making for peace, were only possible in a broad way, and there was no sign of the close connection that now exists between the centres into which are focused the commercial life of Europe and the United States, the Stock Exchanges of London and New York.

Wonderful as it must seem to us, however familiar we are with the fact, the change in the relations to one of international friendship and goodwill depends on the thin lines of cable that span the vast expanses of the dividing ocean, creeping to their appointed ends across the sand and the slime and the rocks that line the sea-floor, down in the great depths tenanted by the sightless fish.

Even now cable laying places a heavy tax on the

engineer entrusted with the work, but the methods employed and the difficulties conquered can be realised best by studying the history of the first Atlantic cable. The project was one of the boldest ever promoted. Lieutenant Maury, of the United States Navy, who took part in the original survey, reflected the scepticism against which the projectors, Mr. (later Sir Charles) Bright, Mr. Cyrus Field and Mr. John Brett, had to contend when he wrote in his report, "I do not, however, pretend to consider the question as to the possibility of finding a time calm enough, the sea smooth enough, and wire long enough, or a ship big enough, to lay a coil of wire sixteen hundred miles in length."

Professor Airy, the then Astronomer Royal, gave it as his opinion that "it was a mathematical impossibility to submerge a cable in safety at so great a depth," and that "if it were possible, no signals would be transmitted through so great a length."

I owe the information to the well-known journalist, Mr. Moy Thomas, that the novelist Thackeray was another of the sceptics. "I have sunk a thousand pounds in the cable," he said one evening in private conversation to Mr. Moy Thomas's father, emphasising the double meaning of the word "sunk" with a wink, and adding that he never expected to see back a penny of his capital, but that he thought it right, on patriotic grounds, to support the scheme.

Bright, at the time when he became engineer-in-chief, was a young man of twenty-four, but he had his splendid optimism, his earnestness, and his enthusiasm to pit against the gloomy prophecies that heralded the birth of the project.

What were the problems the engineers had to face? The distance, in the first place, from Valentia, on the west coast of Ireland, to Trinity Bay, Newfoundland, was no less than 1,640 nautical miles, and it was estimated that a length of cable of 2,500 miles would be required, the total weight of it being 2,500 tons. It consisted of seven insulated copper wires, surrounded by gutta-percha and then by hemp, the whole being armoured with eighteen iron strands, each containing seven iron wires. The length of copper and iron wire all told was 340,500 miles, a length more than sufficient to stretch from the earth to the moon, and enough to engirdle the earth thirteen times. Little was known as to the conditions under which the work was to be attempted. It is true that cables had been laid uniting England and France, and between a few other places, but the depths and lengths encountered were trifling compared with the 2,000 fathoms that were to be met with in the Atlantic. There were all sorts of uneasy forebodings as to the difficulties that might arise. Some, by a curiously false reasoning, believed that with the great pressures existing at these vast depths the cable would never reach the bottom, others prophesied that the effect of the pressure would be to destroy the insulation, and there were many who held that bad weather would make the laying of the cable an impossible feat.

There is something strangely stirring about the enterprise and courage of the projectors of the Trans-Atlantic scheme. American investors provided them with little but sympathy, and the bulk of the capital was subscribed, as we can remember with pride, by British merchants, while both England and the United States lent the assistance

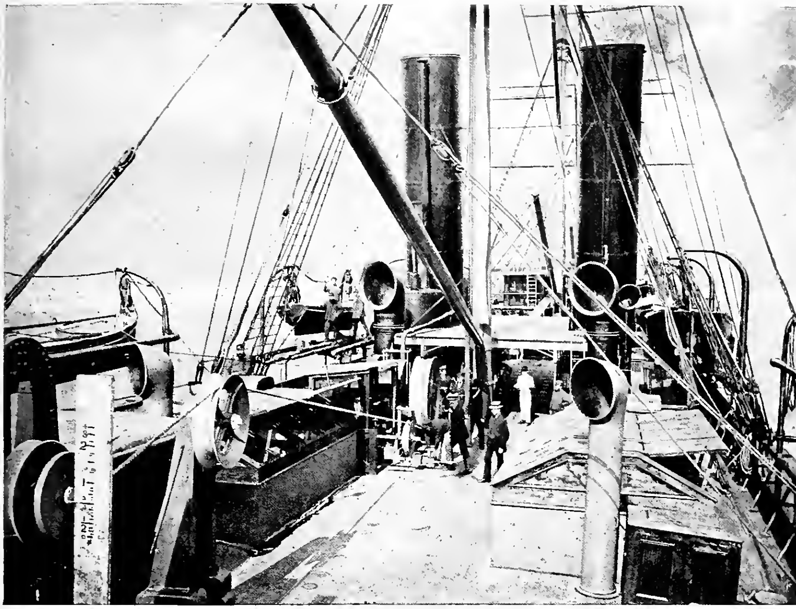


Photo: Messrs. Siemens Bros

THE DECK OF A CABLE SHIP

Note the cable being run out over the pulleys

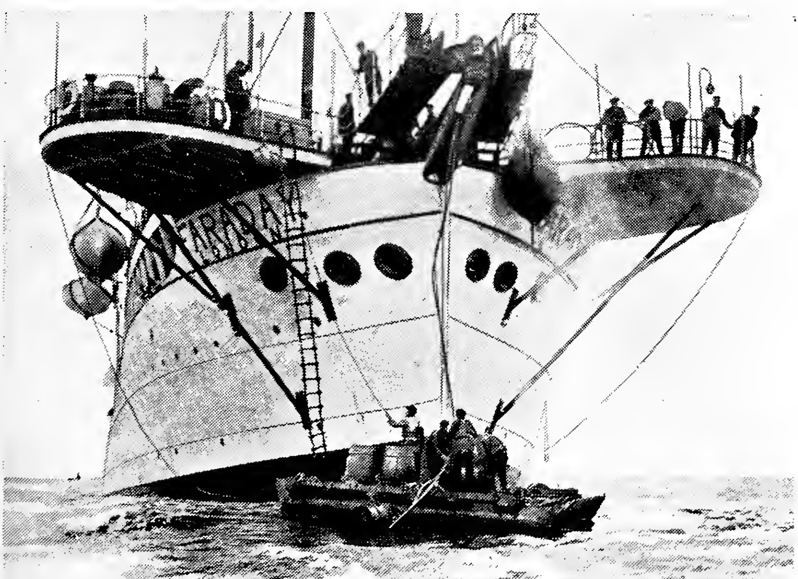


Photo: Topical Press

LAYING THE CABLE

The workmen on the raft are attaching the shore end of the cable to buoys

of ships of their Navy. The British Admiralty placed the *Agamemnon* at the disposal of the company, a coincidence that augured well for the success of the undertaking, for you will remember that, as Æschylus has handed it down to us in his famous tragedy, it was Agamemnon, the King of the Greeks, who is recorded as having been the first in history to flash the news—in his case the news of the fall of Troy—by watch-fires across the hills to those who were waiting to know his fate in far-off Greece.

The first year's attempt I will pass over in a few words. There was a great flourish of trumpets, a trifling mishap occurred at the outset, and when this had been repaired, 380 miles of cable were paid out. Then a mechanic blundered, the cable jammed as it ran out over the unwinding apparatus, it parted, and the attempt that year had perforce to be abandoned.

The event was an occasion of triumph for those who all along had been croaking of failure, but it served only to stiffen the backs of the projectors. They had learnt much from their trials. The cable as it sank to the depths of the ocean they now knew could be controlled, and Mr. Bright, profiting by the year's work, invented a new paying-out gear that should not suffer from the faults that had revealed themselves in the old. Professor Thomson had invented his marvellous mirror galvanometer, and it had been proved that the subjection of the cable to great depths did not interfere with its power of conducting the electric current. Professor Thomson—later Sir William Thomson, and then the world-famed Lord Kelvin, whose remains now rest in Westminster Abbey close to those of Newton—was so greatly responsible for the success of the

cable, and his instrument is one of such extreme beauty, that, though it belongs to the realm of invention rather than to that of engineering, you may be interested to learn the principle on which it works. You know that if a magnet hangs suspended and is surrounded by a coil of wire through which an electric current is passing, it is turned away from pointing north and south. Professor Thomson arranged a tiny magnet and attached to it a minute mirror ; he magnified the effect of the electrical current by using very fine wire and winding many turns of it round his magnet, and then arranged that a beam of light should fall on his mirror. The reflection of this beam of light was caught on a screen, and however little the magnet and the mirror moved, there was a large movement of the spot of light across the screen. It sounds a simple enough apparatus, does it not ? Any boy with a taste for mechanics could put together a rough model in a couple of hours, and yet it was largely this instrument that was destined to make the working of the submarine cable a success. Here is an example of its amazing sensitiveness. Years later, when Mr. Latimer Clark, the electrician whose name still survives as the inventor of a special electric battery, was at Valentia, in Ireland, testing a new cable, he got the two Atlantic cables that met there joined together electrically at Newfoundland, so that he had a length of 3,700 miles of submarine cable to signal through. In his admirable book on "The Story of the Atlantic Cable," Mr. Charles Bright—he of the present generation—tells how Mr. Latimer Clark, who was testing the cable, "placed some pure sulphuric acid in a silver tumbler, with a fragment of zinc weighing a grain or two. By this primitive agency he succeeded in conveying signals

twice through the breadth of the Atlantic Ocean in little more than a second of time after making the contact. The deflections were not of a dubious character, but full and strong, the spot of light traversing freely over a space of 12 inches or more."

The Fury of the Ocean

From this digression, we must return to the story of the second attempt. After a trial trip, during which several important tests were made, the fleet set out for the mid-Atlantic. It consisted of H.M.S. *Agamemnon*, the United States frigate *Niagara*, the *Gorgon*, the *Valorous*, and the *Porcupine*, but this time it started without any public encouragement. There was every prospect of fine weather, but the ships had scarcely been a week at sea when the ocean was swept by as fierce a storm as has ever been experienced in the Atlantic. It seemed as if the ocean were determined not to allow this infringement of its sovereign power. The *Agamemnon* was a good sea-boat, but with the dead weight of cable forward in the bows, her planks gaped an inch apart, and her beams threatened daily to give way. The *Times* correspondent, who was on board, sent to his paper an account of the terrible experience, an account which ranks as the most intensely realistic description of a storm ever written by an eye-witness.

The storm lasted for a week, and during all this time it seemed impossible that the ship could survive. In the midst of the storm, when the heavy cable threatened to break loose and take charge, the *Agamemnon* fell into the trough of the gigantic seas which came on board; the

coal stored on the deck all broke loose, and the deck was a mass of confusion, men, coals, deck-buckets, ladders, and everything that could break loose being awash on the decks. The straining of the vessel was ghastly, as can be gathered from one of the accidents. A marine on the lower deck tried to save himself by catching hold of what seemed to be a ledge in the planks, but, unfortunately, the gap was only caused by the beams straining apart, and as the ship righted they closed again, crushing his fingers flat. The lurch of the ship on this occasion was calculated to the amazing extent of 45 degrees each way for five times in succession. That the ship and her consorts ever survived the terrible buffeting is a striking tribute to the staunchness of her timbers and to the heroism of the officers in charge of her. The storm subsided, and the ships met at their rendezvous in calm water. There was no delay in starting operations ; the end of the *Niagara's* cable was passed aboard the *Agamemnon*, and spliced ; a bent sixpence was placed in the splice for luck, 150 fathoms of cable were paid out, and the two vessels steamed away on their course, respectively to Europe and America. After three miles had been paid out the cable, which was being allowed to run too slackly on the *Niagara*, overrode the unwinding gear, and broke. The vessels returned to the rendezvous, made a fresh splice and started again. This time everything worked well, but after about eight hours' running electric continuity was broken, and it was clear that the cable must have parted.

You have probably been wondering how it is that with the ships many miles apart, out of sight, and the cable resting on the floor of the ocean, a break can be

made known. The problem is not a difficult one. To the far end of each cable was fitted a transmitting and a receiving electrical instrument, and the electricians in charge agreed to send each other electric signals every ten minutes, so, naturally, as soon as the signals ceased to arrive, that is as soon as the electric continuity was broken, it was realised that a break in the cable must have occurred.

The ships put back to their rendezvous, and, on speaking the *Niagara* the *Agamemnon* was amazed to see the flags run up to ask the question, " How did the cable break ? " Tests on board the two ships had shown that the break had occurred at a great distance from the ships, probably on the bed of the ocean, and there were naturally fears that the accident might have been due to some such insuperable obstacle as the presence of sharp-pointed rocks which had cut through the cable. There was no help for it but to begin all over again, and this time it was agreed that if another break occurred when more than 100 miles had been steamed from the rendezvous, the ships should abandon the enterprise, and return to Queenstown.

This time all went well for a while, and when the *Agamemnon* had steamed 112 miles, the moment came to pay out the last flake of the first great coil of cable. The vessel was slowed down; the instrument, fitted to show exactly the strain on the cable, was recording less than a ton of pressure when the cable parted. The storm that had nearly sunk the *Agamemnon* on her way out had shifted the flooring in the tank in which the cable was stored, had damaged it severely and made it unable to bear the strain. For the second time the attempt was abandoned.

The Last Attempt

There is small mercy for the engineer who fails in his project. He is treated by the public as the Spaniards treat a toreador who misses his blow in a bull-fight, or as the Italians treat a singer who makes a false note, and when the year following the time came for a fresh start to be made, the squadron, as the *Times* account tells us, "seemed rather to have slunk away on some discreditable mission than to have sailed for the accomplishment of a great national scheme." Their mission was spoken of as a "mad freak and stubborn ignorance." It was "regarded with mixed feelings of derision and pity." The ships arrived without accident at their meeting-place in mid-ocean, and on Thursday, July 29, 1858, the splice was made, and the cable dropped overboard. Things went smoothly, and the first alarm was when a monster whale was seen approaching the cable at the rate of an express train. This leviathan of the deep appeared to be making straight for the cable, but at last, to the relief of all on board, it passed astern, just grazing the cable, where it entered the water.

Within a few hours there was another dramatic incident. An injured portion of the cable was discovered about a mile or two from the part that was being paid out. There were twenty minutes to spare, and the damaged part was being hastily cobbled up, when Professor Thomson reported that the electrical continuity of the line had ceased. Hurriedly the cable was cut above the damaged part, the ship was stopped, and the cable was let go as slowly as possible just to prevent its breaking from the strain. All eyes were fastened on the hold where the electricians were

hurriedly making the necessary splice. The time was insufficient, and the paying out of the cable had to be stopped. The dynamometer indicated a steadily increasing strain that rose to over two tons as the ship hung on to the end of the cable, but the splice was finished, the strain was released, and the spliced portion passed safely over the side. Within a few minutes, however, Professor Thomson reported a break. Anxiously, the ship watched, hoping against hope for a return of the signals, and in a few minutes the signals returned as well and strong as ever. The fault, it was found later, was in the recording instrument, not in the cable at all, but it gave to all on board an anxious time.

Progress was now continuous, but when over 130 miles of distance had been made, it seemed that the ever-jealous sea, the sea of which Homer has said that no man may reap its harvest, was again to wreck the enterprise. The wind blew to a full gale, raising heavy waves and placing a terrible strain on the cable despite the zealous efforts of the engineers, to whom fell the lot of controlling the unwinding gear. Saturday, Sunday and Monday morning the gale lasted, and on Monday afternoon the stupidity of man was added to the risks of the undertaking. A three-masted schooner was seen bearing down upon the *Agamemnon*. When she was within half a mile, she altered to a course that was to bring her across the *Agamemnon's* bows, and a collision that might, and almost certainly would, have proved fatal to the enterprise seemed inevitable. The *Valorous* hurried along, and fired a gun to stop her; the *Agamemnon* also fired to tell her to heave to, the *Valorous* fired a second and third time, but to no effect, and to avoid collision the *Agamemnon* had to resort to the desperate

expedient of altering her course. The cable, however, bore the strain, but it was small consolation to the *Agamemnon* that the vessel saluted and cheered when she had discovered the work on which the *Agamemnon* was engaged. The danger from this source was not, however, even yet passed, for in the grey light of the following morning there was a large American barque seen standing right across the stern of the *Agamemnon*. It was no time for half-measures, or for nice courtesies. The *Valorous* rounded to in the most warlike attitude, and fired gun after gun until the vessel, in evident alarm, and no doubt in considerable indignation, hove to. At last shoal water was reached; at midnight, on Wednesday, the 4th of August, the Skelligs light was made in the distance; on Thursday the bold mountains of Valentia came into view, and the *Agamemnon* proudly anchored in Douglas Bay, conscious of the good work done, and overjoyed to hear from the *Niagara* far across the Atlantic that she, too, was preparing to land her end of the cable in safety.

Of the congratulations lavished, and justly, on the engineers, of the messages sent between Queen Victoria and the President of the United States, I have no space to write, but the first message sent across the completed cable by the directors in Europe to the directors in America ran:

"*Europe and America are united by telegraphy. Glory to God in the highest, and on earth peace, good will toward men.*"

You may be surprised at my giving so much room to the details of an achievement carried through fifty-five years ago. I have done it partly to pay a tribute to the memory of a gallant company who had trust in themselves

and in their work when all around them doubted, partly because of the intense dramatic interest of the story, but principally because the work of cable laying to-day is essentially the same as it was in the days when the *Agamemnon* and the *Niagara* made their pioneer attempt. Improvements have been made in the gear, but it remains broadly of the original type, though when the *Great Eastern*, the wonder-ship of Brunel, was pressed into the cable service, means were devised for picking up a broken cable no matter what the depth to which it was sunk. Except for the public scepticism, the difficulties and dangers are to-day much the same. There is the chance of tempestuous weather to be encountered, the danger of other vessels fouling the cable, the risk of the cable being sawn through by sharp rocks on the ocean bottom, or breaking, owing to an undue strain. There is much that could be written of the risks to which the cables are exposed even when they have been well and truly laid. The cause that finally wrecked the first cable, the use of excessive electric currents, has been successfully surmounted, but there is still the mischance that an anchor may foul the cable and tear it to a hopeless tangle. Another difficulty that has to be met with is that the cable gets covered with marine life, barnacles, and so forth, and several of the monsters of the deep, such as the sawfish and the teredo, appear to regard the cable as their larder, while sharks have on more occasions than one savagely bitten the line, leaving a few teeth in the intestines of the sheathing as a memento of the encounter.

For an account of the delicacy and mechanical beauty of the many instruments used in connection with submarine telegraphy, for the operation of which it is necessary only

to use the smallest currents, you must turn to Mr. Charles Bright's works on telegraphy.*

I must dismiss, too, in a few words the grand conceptions of Mr. Bright for an All-Red Cable Route that would maintain a band of cables throughout the British Empire entirely under British control, and of Sir Henniker Heaton, who has dreamt of establishing a cable service of penny-a-word telegrams throughout the confines of our Empire. Of their tireless efforts to realise these great ideals you can read from day to day in the newspapers.

There is one more aspect of submarine telegraphy, however, to which I would refer. The cables pass through the desolate wastes of ocean, and in reading of these far-off waters and lands one touches on strange experiences that one marvels at and must leave unexplained. In the middle of the Pacific Ocean there lies a group of islands among which the Pacific cable emerges from the ocean. The land is surf-swept, a haunt for the most part of sea-birds, but it was carefully surveyed years ago at the time the Pacific cable was projected. It is now only a few months ago that the question of the ownership of one of these islands, Palmyra Island, was brought into dispute, and I had the task of trying to discover its early history. I am indebted to the editor of the *Morning Post* for permission to reprint here one of the results of my research.

"The contemporary story of Edmund Fanning's discovery of Palmyra Island, which is contained in his 'Voyages Round the World' (New York, 1833), is not," I then wrote, "without interest at the present moment.

* "Submarine Telegraphs" (Crosby Lockwood and Son), "The Story of the Atlantic Cable" (Hodder and Stoughton), and "The Life Story of Charles Tilston Bright" (Constable and Co., Ltd.)

After describing his discovery and naming of Fanning Island and Washington Island, Captain Fanning gives the following account of his experiences on June 14, 1798:

"'At nine o'clock in the evening, my customary hour for retiring, I had, as usual, repaired to my berth, enjoying perfect good health, but between the hours of nine and ten found myself, without being sensible of any movement or exertion in getting there, on the upper steps of the companion-way. I suddenly awoke, and after exchanging a few words with the commanding officer, who was walking on deck, returned to my berth, thinking how strange it was, for I never before had walked in my sleep. Again, I was occupying the same position, to the great surprise of the officer (not more so than to myself), after having slept some twenty minutes or the like; here, upon observing the glittering stars overhead, and feeling the night air, I was preparing to return to the cabin, after answering in the affirmative his inquiry whether Captain Fanning was well. Why, or what it was, that had thus brought me twice to the companion-way I was quite unable to tell, but that there should not be any portion of vigilance unobserved by those then in charge, I inquired how far he was able to see around the ship? He replied that, although a little hazy, he thought he could distinctly see land or danger a mile or two, adding that the look-out was regularly relieved every half-hour, in reply to my question if such was the case. There was something very singular, and, with a strange sensation upon my mind after what had passed, I again returned to my berth. What was my astonishment on finding myself the third time in the same place! Yet with this addition: I had now, without being aware of it,

put on my outer garments and hat; it was then I conceived some danger was nigh at hand, and determined me upon laying the ship to for the night.'

"Captain Fanning describes how he then slept peacefully till daylight, when he came on deck, and the *Betsey* proceeded on her voyage. He continues:

"'All was activity and bustle, except with the helmsman; even the man on the look-out was, for a moment, called from his especial charge . . . This induced me to walk . . . to the lee quarter, not expecting, however, to make any discovery, but solely to take a look ahead; in a moment the whole truth flashed before my eyes, as I caught sight of breakers mast high directly ahead, and towards which our ship was fast sailing. Instantly, the helm was put a-lee, the yards all braced up, and sails trimmed by the wind, as the man aloft, in a stentorian voice, called out: "Breakers! Breakers ahead!" . . . The ship was now sailing on the wind, and the roaring of the herculean breakers under her lee at a short mile's distance was distinctly heard, as the officer to whom the events of the past night were familiar came aft to me, and with the voice and look of a man deeply impressed with some solemn convictions, said: "Surely, sir, Providence has a care over us, and has kindly directed us again in the road of safety. . . . Why, sir, half an hour's further run from where we lay by in the night would have cast us on that fatal spot, where we must all certainly have been lost. If we have, because of the morning haze around the horizon, got so near this appalling danger in broad daylight, what, sir, but the hand of Providence has kept us clear of it through the night?" With him I perfectly agreed.'"

CHAPTER XVIII

MARINE SALVAGE—THE *MILWAUKEE* AND THE *SUEVIC*—SAVING BULLION FROM THE *OCEANA*

THERE are few of us, indeed, who have not felt the romance of the sea. Most of us at one time or another have pictured ourselves as pirates, sailing under the flag of the skull and crossbones; or, if our thoughts have turned to kindlier channels, we have in imagination pursued the pirates to their lairs, and set the sea free for peaceful traffic. Others of us, steeped in the romance of hidden treasure, have revelled in the adventures of Stevenson's "Treasure Island," and, maybe, have enjoyed reading the adventures experienced by Mr. E. F. Knight and his friends when in actual fact they set out in search of hidden treasure on the Island of Trinidad.

An account of the salvage work achieved during the last twenty-five or thirty years would amaze the sea-captain of a hundred years ago. Scientific knowledge has advanced so rapidly that the impossible of yesterday is the practicable of to-day. Astonishing feats of ship-surgery have been accomplished, but these come rather into the sphere of the shipbuilder than of the salvor.

There was the case, for instance, when the *Netherston*, with a cargo of benzine on board, blew up in the China Seas. Her decks were blown out of her and her hull buckled in; the vessel appeared a hopeless wreck, and she was

abandoned off Singapore. All the bright metal, the copper pipes, and so forth were looted by the natives, but the engineer who had been sent out by an enterprising British firm was undaunted by these difficulties. He strengthened the ship by running girders across her. He substituted iron steam-pipes for the copper ones that had been taken away, replaced the decks with heavy wooden planking, and covered them with canvas to keep the water out, and within a month of taking charge at Singapore he had the derelict on the high seas on her way back to England.

I might quote you case upon case of the way in which the salvage engineers have had to call on the varied resources that the engineer has at his disposal. He is, in fact, the apostle of the pump, of the centrifugal pump that he uses to drive water out of a vessel when he has repaired the rents in her side, or when he builds a coffer-dam round the vessel to repair the damage before attempting to raise her, and of the air-pump by which he can force the water out of a ship's hold and float her into safety.

A case, however, to which I want to refer rather more fully is that of the *Milwaukee*. She was a large freight vessel, and came on to the rocks off Peterhead. With bad weather and the full force of the Atlantic swell, she bumped her nose heavily on the rocks, and when the Liverpool Salvage Association came to try and effect a rescue, her bows were battered beyond repair. This, if ever, was a case for enterprise. The salvage officers realised that with the equinoctial gales coming on, haste meant everything. There was, they saw, one chance to save her. If only the bulkheads—the partitions that divide a ship into watertight

compartments — would bear the pressure of the water, it was, they thought, possible to jettison the damaged bows, and bring the after end safe into port. Anyway, the experiment was worth trying, and it is no use for a salvage officer to be backward about taking risks. A cordon of dynamite was passed round the vessel just forward of the bridge, the explosive being enclosed in rubber tubes, and the object being to protect the bulkhead that was eventually to have to support the full pressure of the sea. As then in salvage work the undertaking was of a pioneer character, and it was a case of the salvage officers backing their opinion for heavy odds against the unknown, but when the 520 lbs. of explosives had been expended, the after-part of the vessel slid quietly into deep water, and no difficulty was experienced in towing the vessel—which, by the way, used her own steam as an auxiliary—into safety. The work was a fine tribute to the builders, as well as to the salvage officers, for when the question was referred to the builders as to whether the bulkheads were strong enough to withstand the strain, they had no hesitation in saying emphatically that this would be the case. Incidentally, there was another testimony to the efficiency of their work, for it needed 140 lbs. of dynamite to sever the keelson, which may be regarded as the backbone of the ship.

The salvage of the *Milwaukee* created a sensation in the shipbuilding world, for when the after portion of the vessel had been salved, it was an easy matter to fit new bows.

It was only a comparatively short time later that the *Suevic* came to grief off Cornwall. She had on board a cargo of frozen meat, and as her bows were hopelessly locked on the rocks the Liverpool Salvage Association

pursued the policy that had been so successful on a previous occasion, cut away the damaged bows with dynamite, and towed the after-end of the vessel back into Southampton. The work was a notable one, for the after-end of the *Suevic* was carried back to port on compressed air, and forced to trust to her decks and bulkheads to carry her weight during the passage. From first-hand knowledge, I know that her crew were nervous about the risk, and that it was only through the infectious courage of the officers in charge that they were willing to serve on board the mutilated vessel. It may, perhaps, be of interest to you to know that Captain Young, the officer responsible, gave it to me as his opinion that the safety of ships at sea would be greatly increased by designing them to withstand a strain from below upwards, instead of primarily, as at present, a strain from before backwards, the idea being that in the event of a ship sustaining damage to her bottom, she should sink until the deck and the hatches above the injured part were even well below water, when air-pumps installed on the upper deck would deliver a continual stream of compressed air, so that on this, as a cushion, the injured vessel could be kept afloat upon her deck until she reached harbour. This was one of the lessons of the *Suevic* salvage, for when the hatches had been specially strengthened, they found that it was strong enough to support this strain, and the inference was made that on these lines a vessel might in many cases effect her own salvage at sea.

My personal connection with the *Suevic* began in October, 1907. I was working on the *Standard* at the time, and the offer was made me to travel round from Belfast

with the new bows. None of us had much idea what the trip would mean, and I remember leaving London one Friday night, expecting to be back in town early in the following week. Bad weather delayed us at Belfast, and it was not until Sunday that our voyage actually started. Throughout the trip, we were ready at any moment to send a message ashore, but, as a matter of fact, we had no opportunity of communicating anywhere until we succeeded in reaching Southampton. Here is the impression of the feat as it appealed to me when I was fresh from witnessing it.

In preface, I should state that the new bows had to be towed from Belfast to Southampton, the broad end foremost, because it was found by experiment that when towage was attempted bows forward the vessel yawed so much as to make the task impracticable.

When the manager for Messrs. Harland and Wolff, I then wrote, gave the order to cast off from the Alexandra Wharf in the Queen's Island shipbuilding yard at Belfast he instituted the third stage of a feat unique in the history of marine engineering.

The first achievement, the blasting off of the fore-end of the ill-fated *Suevic*, when she struck on the Stag Rock, has been fully reported; mention has been made of the building and launching of the new fore-end in Messrs. Harland and Wolff's yards at Belfast, and now the third task, that of towing this portion from Belfast to Southampton, has been satisfactorily completed. This is a feat of which the builders may well be proud. Two gales and contrary winds, which have lasted almost throughout the voyage, have subjected the bulkheads to excessive strain,

but not a drop of water found its way into our bilges. The strength of adverse winds and swell was so great that on two occasions the tugs became quite unmanageable, while the swell tore two great V-shaped pieces out of the plates which project out before our bulkheads.

The voyage was full of incident, and caused great anxiety to those responsible for the vessel's safety. Before we got properly out of Belfast into the open sea, we were forced to lie by for about twenty hours, waiting for the wind to become favourable, or at least to abate something of its fury, and it was not until early on Sunday morning that we paid out our deep-sea tackle to the tugs, hove anchor, and definitely started on our way. The weight of the *Suevic's* fore end made it necessary to have specially designed towing gear. Four lengths of the *Suevic's* anchor chain were utilised and made fast on either side to two pairs of bollards, while their extremities were joined to an enormous ring. Fastened to this by specially forged shackles were two left-handed 5-inch cables, which completed the towing-gear on board the *Suevic*. When we were ready to make our start for the open sea, the *Blazer* (Captain Jones) and the *Pathfinder* (Captain Foster, the designer of the towing gear) came alongside. From each tug a "messenger" brought up a 5-inch cable furnished with a shackle similar to ours. The two pairs of shackles were placed together, the cotter pins were driven in and hammered over to keep everything in position. The order, "Let go!" was shouted out, and passed back to the man in charge of the windlass, and with a heavy splash the wire cables dropped overboard and the tugs steamed out in front, while our anchor was still fixed to ensure that all was in order to bear the

great strain that was to be put upon the gear. Two 14-inch manila cables completed the equipment, giving to our tackle, in all, a length of 170 fathoms.

It was about 7 P.M. on Sunday when we first experienced severe weather. Without any warning, half a gale sprang up from the south-west, and torrents of almost tropical rain swept our decks, driven with the full force of the wind. Such was the violence of the storm which met us almost opposite the Chickens that the rain forced an entrance into the captain's cabin through the closed door, and settled in large pools upon the floor. By 11 o'clock the violence of the storm had abated, and the officers who had hurried upon the bridge ventured to leave the ship in charge of the watch.

The respite was short-lived. By 4 o'clock in the morning the storm redoubled in fury, and for several hours we drifted astern at between three and four knots, while for the first time the *Suevic* began to pitch and toss in the heavy seas. By 7 A.M. it was discovered that we had drifted back some thirty miles. We at once signalled to the accompanying tugs to put us upon the starboard tack, but their reply was that they were unmanageable in the gale. On board the *Suevic* life-boats were made ready in case of emergency, and we sent a message: "We are casting off *Pathfinder's* hawser," our object being to allow the *Blazer* to pull straight ahead, and so avoid the necessity of the two tugs having to work at a mechanical disadvantage in order to avert collision. Before, however, the order was carried into effect the weather showed signs of improving, the tugs again came together, and we slowly moved forward, churning the sea in front of us into an

expanse of swirling foam. Though we had signalled the Chickens at 9 o'clock with rockets, it was past midday on Monday before the Isle of Man was lost to view.

During the storm I went down into the hold abaft our bulkhead. Behind the massive red steel plates were enormous beams of Pensacola pitch-pine wood, 14 inches square, specially arranged to bear the strain of towing the vessel stern first into Southampton. All through the voyage two men stood by the bulkheads with candles mounted on slips of pine wood, perfectly indifferent to the roar of the waves against the plates, which sounded like peals of thunder reverberating through the hollows of the vessel. They were watching the plates intently, and had instructions to inform the officers on the bridge at the first sign of leakage, so that pumping operations might at once begin. In the uncertain light cast by the candles, one could barely distinguish the enormous beams looming into the distance, and beyond them the pipes of the salvage pumps, swollen with water, and thus ready to start emptying the bilges in case of emergency.

Serious as the first storm on Sunday night had proved, the full force of the Atlantic swell which we experienced off the Cornish coast for twelve hours gave a far severer test to the seamanship of our strange craft. At 2 P.M. on Wednesday we began to roll; by 4.30 we were rolling 12 degrees to 15 degrees, having a few degrees list to port. By 6, we registered 23 degrees, and before 9 o'clock the clinometer had recorded 27 degrees. With the first big roll at 6 o'clock, there was a loud crash of broken glass and crockery. Nothing that was breakable survived in the cook's galley, and everything that could move in the

ship rolled from side to side. The refrigerating pipes, which we were carrying in the hold as ballast, crashed together, raising an incessant din, and, though we had the fiddles on the solitary table available for messing, nothing was able to withstand the motion. Even the 12-inch pipe of the salvage pump, which was firmly lashed to the hatches, broke loose during the night, and had a little play until it was secured. All the officers were on the bridge, and Mr. Beattie, the engineer in charge of the pumps, stayed up all night to see that the jacks kept the chains by which his engines were secured fast and taut. Before midnight a roll of as much as 33 degrees was obtained, and this on a Bell's patent clinometer, which, destroying the effect of inertia movements, gives the true reading, a reading some 10 degrees lower than that obtained by the ordinary pendulum clinometer. Sleep under these conditions was out of question, and none of us turned in until we rounded the Longships, and the heavy Atlantic swell was no longer on our beam.

During the routine of the voyage, while we were beating up against adverse winds and contrary swell, there was an extraordinary want of reality about the ship. The look-out man always hesitated whether to announce a vessel as being on our port or starboard bow. The smoke from the little donkey engines that worked our winches made our decks resemble those of a torpedo boat, while the funnels for the salvage boilers in front were the very image of the primitive engines designed by Watt and Stephenson. One started to go for'ard, and was brought up against a void amidships, with nothing but the towing gear in front and a great expanse of boiling foam 30 feet or 40 feet beneath. The absence of all vibration from the engines

completed this illusion of unreality, while as the seas struck our bulkheads a shiver ran through the ship that was scarcely distinguishable from the shocks the *Suevic* experienced when she bumped on the Stag Rock off the Lizard.

During the whole of the voyage we have been fortunate in having a brilliant moon that has often enabled us to pick up the outline of the distant shore. It was early on Thursday morning that we made the Lizard on our port bow, but as it was high tide, it was impossible to see how much remained of the ill-fated *Suevic,* and a few hours later we sighted Falmouth, where the hapless *Mohegan* struck upon the Manacles in 1898. With the exception of a few hours this morning, when the ship was caught in a mist, the weather in the Channel was all that could be wished. As we passed by Portland we ran through a little fleet of torpedo boats that studded the sea with patches of lights as far as the eye could see. By 1.30 we were opposite the Needles, and after four hours we had only just passed Hurst Castle.

When I got on board the *Ajax,* the tug that brought us ashore, it was still uncertain when the *Suevic* would be able to make her berth. She had yet some 20 miles to go, and the ebbtide had not ceased running, though it was greatly reduced in force. Captain Dunlop informed me, as I was going, that he hoped the ship would reach the Old Extension by 9 o'clock this evening, or, failing that, by 1 A.M. to-morrow. There she will disembark the heavy gear she has brought with her as ballast, and will then go into dry dock to be joined to the after-portion of the vessel. The new forepart will be floated into its position, and stopped at the required distance from the

old to make up the total length of the original *Suevic.* When this has been done, only the simplest portion of the task remains. The two parts of the *Suevic* will be fitted together in dry dock in Southampton, and there the whole structure from the keel upwards, including the plates in the shell, the decks, the double bottom, and also the keelson, on which so much of the resisting power of a vessel depends, will occupy exactly the position which was assigned them when the original *Suevic* left the builders' yards in 1900. Extra riveting, however, and an increase in the number of rivets that are to be driven in by mechanical means will make the vessel even more resistant to the strain and stress of weather than she proved herself to be when she lay bumping heavily on the jagged abutments of the Lizard. Finally, to ensure that the strength of the new structure may be maintained, a new section of the keel to overlap both new and old portions of the vessel will be added.

So ended my connection with the *Suevic,* one of the pleasantest experiences that I have ever enjoyed.

The next opportunity I had of seeing salvage work at first hand was last year, when the Liverpool Salvage Association were at work salving the specie that went down with the P. and O. ss. *Oceana* after she had come into collision with the *Pisaqua.*

On this occasion I was fortunate enough to be on board the *Ranger* on the first day when she made a really successful haul. As this work is entirely different from the two classes of salvage that I have hitherto described, and as diving is an essential part of several branches of engineering, I am including the impression I wrote at the time when I was fresh from witnessing the work.

The *Ranger*, the well-known salvage ship of the Liverpool Salvage Association, I wrote from Newhaven, surpassed her own record this morning, and in an hour's work recovered ten boxes of gold worth about £40,000, and a smaller box, believed to contain silver articles. By the courtesy of Captain Young, I was able to go out on the *Ranger* and watch the actual diving operations from the *Beaulieu*, which is accompanying her, and from whose decks the salvage work is being done.

We left our berth in Newhaven Harbour about 2 o'clock this morning. There was a good sailing breeze from the south-west, and the speed with which the clouds were scudding across the face of the moon suggested the probability of a stronger breeze that would seriously interfere with diving operations. The object was to reach the scene of the wreck so much in advance of the low-water-slack that the *Beaulieu* could be moored in position for work to begin at slack water.

The night air made a light breakfast at 4 A.M. a welcome interlude to standing on deck watching the rays of the Beachy Head light flash along the coast, and the lights of the *Royal Sovereign* and the lightship stationed by the wreck grow plain and distinct. The *Beaulieu*, that had followed us up from Newhaven, was alongside before 5 o'clock, and as the *Ranger* had now let her anchor cable clatter its way out through the hawse-pipe, we transferred to the tug, and proceeded to the actual wreck.

The *Oceana* presents special salvage difficulties, for, it will be remembered, she was run over, after she had foundered, by a sailing vessel, and her decks have been littered with debris. In the circumstances, it is particularly impor-

tant that the salvage vessel should be brought within a few feet of the ideal position. After anchoring as near as possible to the desired spot a line was made fast to the two remaining masts of the *Oceana*, and with this, as a sort of bridle, the nose of the *Beaulieu* was drawn close in, so that her bows were exactly as wanted. To steady her, and to ensure that she should not shift as a result of changes in the tide, a line was passed from the stern to a buoy that is moored close by.

To the outsider the period of waiting that follows the preparation is unpleasantly nervous work. Stationed on the bridge you have the double advantage of being out of the way, and of getting a good view of all proceedings. There are a dozen or eighteen men scattered about the tug. Two or three of them are standing chatting idly by the pumps which are to supply the divers with air. Half a dozen of the crew are in the *Ranger's* boat, which they have tied to one of the *Oceana's* masts, waiting to run a line, or to get what may be wanted from the *Ranger*. The rest, the officer in charge among them, are in the bows watching the water seething as if in a cauldron, with the weight of the tide catching the sunken ship and eddying round and over it. The divers are on the bridge, broad-chested men of middle height. They have an inchoate appearance. The khaki-coloured diving suits recall the rough cloth hose of a shrunken shanked Elizabethan, their red woollen caps suggest the Neapolitan boatmen, and the serviceable sheath-knives which they carry in their belts indicate the brigand. They sit waiting on the bridge, taking no particular interest in the proceedings, except in so far as the leading line to the hold is concerned. There

is nothing to say except that the tide is still running strongly. The breeze which threatened to strengthen has as yet not done so. One or other of them at last makes a move, saying that he may as well see what it is like. He repeats the remark a minute or two later, moves down from the bridge on to the narrow deck, and is helped into his heavily weighted boots. Someone calls to the men at the pumps just to "blow through." The handles are twirled rapidly, the hissing of the air as it rushes through the pipes to the helmet indicates that all is well, and the men steady down to a rhythmic stroke. Two large lead weights are attached to the diver's shoulders; the life-line is tied round his waist; his helmet is screwed home; it is tapped by the "dresser" to let him know that everything is made fast, he is helped over the ladder at the ship's side, and he is there in the water, with helmet still emerging for a few seconds, and he plunges a little, like a large, ungainly fish. As he disappears beneath the surface his helmet throws out large bubbles of air; as he goes deeper the bubbles of air break up into little globules, turning the sea milky.

The men who have the diver's life in their hands now claim attention, the two of them who are turning the wheels of the pump with mechanical regularity, and are going to keep the same steady motion for an hour, and the two at the ship's side, one of them feeling the life-line as a fisherman feels for a bite, and the other paying out the air-tube, keeping it hand-tight to prevent fouling. In watching the arrangements for the first diver, one scarcely notices that the other is being helped over the side, and that he has gone below to co-operate in the recovery of the bullion.

A fresh and more rational interest attaches to the

bubbles as the officer forward remarks that the tide cannot be very bad down below, as the bubbles are coming up almost straight, and you look to see how the *Ranger* is lying to her anchor, and compare her direction with the movements of the bubbles. It is about 6.40, and the wind is blowing strong enough to make it feel chilly on the bridge and to give a slight roll to the *Beaulieu* as she pulls at her cables, but not enough to give appreciable motion to the *Ranger* lying a couple of hundred yards away, or to put white crests on the waves. There is a hail from one of the men holding the life-line, "Lower away!" It is hardly correct to speak of it as a hail. It comes rather in the tone in which an officer makes a trifling alteration in the course he has set, and the men in charge of the little derrick forward lower a chain along the guide line that leads to where the bullion is lying. The chain, though we cannot see it, is caught by one of the divers and passed on by him to his mate, who is working some few fathoms beneath him, and the man at the life-line gives the instruction, "Haul away!" The men in the bows haul on the rope; it catches for a moment, is cleared by the diver below, and in a few seconds a box of specie can be seen on the surface of the water. A couple of turns are taken round the winch, there is a cloud of steam at the side of the ship, and the box numbered and marked "XOX, Bombay," is gentled over the side. Before the box is on deck the man at the life-line sings out, "Lower again!" and so the process continues till one loses all sense of uneasiness as to the fortunes of the men below, and forgets all sense of their danger in the interest of speculating as to whether they will beat their previous day's record.

It is quick work bringing up specie, once the start has been made. I timed the men at the job, and on one occasion a box of gold was on the deck within $2\frac{3}{4}$ minutes of the chain being passed over the side. The work on the *Oceana*, where the men have to support a pressure of 40 lbs. to the square inch, in addition to the atmospheric pressure, is very exhausting. At the end of an hour's work they had brought up eleven boxes, ten of them containing gold. The weight of the metal was such that, when it was all collected on the starboard side, it gave the tug an appreciable list. I feel rather proud of being able to say that I have been on a boat which had a considerable list owing to the gold packed on her deck. While it was being brought up there was constant communication between the *Beaulieu* and the *Ranger*, all conducted by semaphoring. It is matter of pride with the officers and men of the Liverpool Salvage Association that their discipline and knowledge are such that they can do their work silently. There is no shouting of orders on board. Each man in a responsible position is an expert at his work, knows what is expected of him, and does it.

The only sign of hurry that I saw to-day was when the divers came on board. It is a struggle for them to get up the ladder, with their heavy weights when they are already exhausted, and they are quickly helped on board and released from their helmets. When the divers came up to-day at 7.40 they were thoroughly pleased with their work, and as they climbed back to the bridge their first demand was for a pipe of tobacco. The effect of the strain is curious. It amounts to mere fatigue, the pressure to which the divers are subjected while working

below making the same sort of demand on them as severe exercise.

They described to me the method of their work in this particular instance. One of them gets hold of the cases in the bullion room, while the other works at a lesser depth, sees that his lines keep disentangled, acts as a channel of communication between him and the ship, passes the chain on that is let down from above, and guides the salved material up until it is clear to be lifted to the surface. It was a source of satisfaction to them to find that they had stayed down as long as there was any chance of doing useful work. Five minutes after they were back on board, the tide was running with a strength that indicated clearly enough to all on board the *Beaulieu* that the conditions below must have been such as to make any further work than the men had done impossible. Even during the time that they were working the stream of air bubbles moved clean away from the tug, so that it was scarcely possible to recognise where they rose to the surface.

The *Beaulieu*, her work done, returned to the *Ranger*, and the bullion was transferred. And so we returned to Eastbourne. Shortly after I reached the shore I looked back, and saw the *Ranger* and the *Beaulieu* returning to the scene of the wreck with a view to resuming operations at the slack of high water. Unfortunately, it was found that the strength of the current then was such that the attempt had to be abandoned.

The *Ranger* is an old Navy ship. She was adapted some twenty years ago to her present purpose, and has a full equipment of the latest pneumatic tools. The pumps she usually carries—they were at the moment landed

at Newhaven, so that her decks might be clear for the work on the *Oceana*—are run by internal combustion engines and can deal with 3,500 tons of water an hour. She also carries a motor launch, and among the best-known salvage operations in which she has done service are those undertaken in connection with the *Montagu*, the *Gladiator*, the *Suevic*, the *Hibernia*, and the *Minnehaha*.

From these accounts, which are but few out of many, that I have been able to put before you of salvage work, you will have realised how dependent the salvage engineer is on the elements for the varied tasks that he finds set him. It is seldom that any two jobs on which he is engaged are alike. He must go to the scene of the disaster that awaits his services, and, with the equipment he carries with him, he and his crew must, if need be, take their lives in their hands, and try to wrest from the sea the spoil it is threatening to devour. The master of the salvage vessel must be unrivalled in resource. With a perfect seamanship, a sound knowledge of engineering principles, and an unerring instinct to guide him as to what is and what is not practicable, he must be prepared instantly to lay his plans, and to put them into execution, and the whole time he is at work he will be harassed by the feeling that, after all, through no fault of his own, the sea may rob him of his prize at the moment he thinks it to be within his grasp. Without fear of contradiction, one may safely assert that there is no man that puts to sea that is as adequately trained for the work he has to do, no everyday engineering task that places so constant a strain on the men who are engaged in it, and no branch throughout the wide range of engineering practice that is so full of romantic interest.

CHAPTER XIX

LIGHTHOUSES—THE EDDYSTONE AND THE SKERRYVORE—PILE LIGHTHOUSES AND BUOYS

Professor Archibald Barr, when he was President of the engineering section of the British Association last year, considered in his presidential address an aspect of his subject that should be constantly in the minds of every engineer. He was speaking of the artistic side of engineering, and contended that a structure of any kind that was intended to serve a useful end should have the beauty of appropriateness for the purpose it is to serve. It should tell the truth, and nothing but the truth, and if its character be such that it can be permitted to tell the whole truth, so much the better. It should be beautiful in the sense in which we commonly use the term with respect to a machine, for a mechanical device is beautiful only if it strikes us as accomplishing the end for which it was designed in the simplest and most direct way. Among many other illustrations of his point he referred to ships, reminding his hearers that there was a time when the hulls and riggings and sails of ships were lavishly ornamented, but that now the figurehead, the last remnant of barbaric taste, has disappeared. This and other examples, he argued, illustrated the contention that the attainment of the highest efficiency brought with it the greatest artistic merit.

Professor Barr's remarks came into my mind when

I was trying to analyse why it is that the lighthouse appeals so strongly to our imagination. It is partly, no doubt, from its steady rhythmical performance of its functions that make it possible for ships to go safely about their business in the darkness of the night. There is the mystery, too, that surrounds the loneliness of the men living solitary amid a waste of heaving water; but the lighthouse attracts us chiefly, I think, because it comes up to Professor Barr's standard of artistic excellence, by accomplishing the end for which it is designed in the simplest and most direct way.

The origins of lighthouse construction are lost in antiquity. There is the beautiful passage in the "Iliad" where Homer, describing how Achilles seized his shield to go and avenge the death of Patroclus, writes:

"The huge and massy shield he next uptook,
Wherefrom as from the orbed moon stream rays,
So stream'd the light; or as to seamen flames,
In sheepfolds upon mountains kindled high
Show from the ocean whilst storms drive them forth
Loth o'er the fish-filled billows far from home."

The passage, especially when read in conjunction with others, may, I think, fairly be taken as evidence that the idea of the lighthouse was familiar to the early Greeks.

The Pharos or lighthouse at Alexandria, as Stevenson pointed out, may be regarded as the oldest lighthouse. It was looked upon by the ancients as one of the Seven Wonders of the World, and was built in the reign of Ptolemy Philadelphus, about 300 years before the Christian era, and Strabo relates that Sostratus, a friend of the royal

family, was the architect. He describes it as built in a wonderful manner, in many stories of white stone, on a rock forming the promontory of the island Pharos, and says that the building bore the inscription: "Sostratus of Cnidos, the son of Dexiphanes, to the Gods, the Saviours, for the benefit of seamen." He concludes his notice of it by describing the neighbouring shores as low and encumbered with shoals and snares, and as calling for the establishment of a lofty and bright beacon, as a sign for sailors arriving from the ocean to guide them to the entrance into the haven. The light was probably furnished by a fire burnt at the top, a way comparable with what used to be the practice on land lighthouses in this country.

The engineer who undertakes to construct a lighthouse at sea has a difficult and dangerous piece of work before him. He must be able to stand knocking about at all sorts of hours in small boats on rough seas. Day after day he will make the attempt to work on the foundations, but the wind will spring up and at once stop all progress. He must keep his work throughout the whole time of the building in such a state that as little damage as possible will result even if a gale sets in. He must risk the danger of a sudden storm, that will sweep him and his men off the rock on which they are working into the sea. He must so plan his work that as little as possible of it is done at the site, but that the material is ready prepared on shore, and only requires to be fitted into its place.

These difficulties had all to be faced by John Smeaton when he set out to build the Eddystone Lighthouse in 1759, and in addition to these he had to deal with three difficulties: one that the work was of a pioneer character,

another that he had to use sail instead of steam for his ships, and the third that his seamen and workmen were constantly in danger of being seized by the press-gang for the Navy.

The Eddystone reef lies some 14 miles off Plymouth, in the track of the Channel shipping, and before the construction of the lighthouse was a constant source of peril, while since then it has been an invaluable guide to navigation. The first attempt to light it was in 1696, when Henry Winstanley built on it a house of wood and stone. The structure stood for seven years, but in the terrible storm of 1703 it was swept away with Winstanley himself and the workmen and keepers. Then there was Rudyard's house built in 1708, also of wood and stone, but it was burnt down in 1753.

That the authorities recognised the difficulty of the task before them in building a fresh structure is plain from the methods they followed to find an engineer. John Weston had the matter in hand, and, as Smeaton tells us in the excellent account he has left of his work, "he considered that this was not a work proper to be advertised; and that to reinstate it would require a person who from natural genius had a turn for contrivance in the mechanical branches of science; who would not stand in need of being led by the actual execution of a similar performance; but who, solely from the nature of the thing, would be likely to find out the proper methods of executing a building of the like kind with that which had approved itself upon an experience of nearly fifty years; such a person being the most likely to discern how far the late building was defective, how far these defects were capable of a remedy, and what

improvements could be made upon the former construction." Weston approached the Royal Society, and Smeaton, a relatively unknown man, was asked to take on the work. The first question to be decided was whether the lighthouse should be of wood and stone, or entirely of stone. Smeaton strongly favoured the latter view, and carried his point, but the idea among many people was that the strain on the structure from the violence of the waves was so great that only a pliant substance like wood could bear it.

Smeaton's ideal was to erect what to all intents would be a monolith, to build his structure in such a way, in fact, that the strain on any portion of it would be borne equally by the whole building, and with this in view he framed a plan by which all the stones were dovetailed into one another and the whole engrafted similarly on to the rock.

It is hard for anyone not an expert to realise the difficulties against which Smeaton had to contend. The first trouble was that the survey of the reef proved inaccurate and had all to be examined afresh. Then there was the question of the material to be employed. Portland stone seemed a suitable material, but at the time when Smeaton was determining on his choice, the dockyard officials drew his attention to a piece of Portland stone that had just been taken out of the dock walls at Plymouth. The specimen was drilled with a great number of holes, similar to those made by worms in ships, and it was found on investigation, that they were due to a shellfish which made an entry into the stone, and then, as it grew, proceeded to enlarge the recess in which it lodged. Eventually, a satisfactory stone was selected. On August 5, 1756, the work was started, and a beginning was made to cut into

the rock for the foundations. And here a fresh point arose. While matters could clearly have been expedited by making use of gunpowder, Smeaton decided that there was a danger that its use might weaken portions of the reef that were required for building into the structure, and, therefore, arranged that all the cutting into the reef should be done by hand. The work proved troublesome in the extreme, bad weather continually causing great waves to break upon the reef, but before the end of the season the chief part of the excavation necessary had been accomplished.

During this first year's work on the Eddystone Smeaton and his workers narrowly escaped shipwreck. It was on one of the many days that they had found it too rough to land upon the rock. As Smeaton writes:

"For my own part, having been up most of the former night, and a good deal fatigued in lending a hand to the forenoon's operations of this day, I went down to my cabin, and as it had been raining as well as stormy, I disencumbered myself of my wet clothes, intending to repose till I heard we were come to an anchor in Fowey Harbour. For a space of about three hours I had the satisfaction to hear everything going on well overhead; and it was no small addition thereto when I heard those on deck were altering their course in order to run into the harbour; but suddenly an universal *clamour* and *alarm* arose, insomuch that I ran upon deck in my shirt, it then raining hard and blowing quite a storm. It being very dark, the first thing I saw was the horrible appearance of *breakers*, almost surrounding us: John Bowden, one of the seamen, crying out, 'For God's sake, heave hard at that rope if you mean to *save your lives*.' I immediately laid hold of the rope at

which he himself was hauling, as well as the other seamen, though he was also managing the helm ; I not only hauled with all my strength, but calling to and encouraging the workmen to do the same thing, in as little time as I have been describing our situation the vessel's head was brought round, so that we no longer faced the breakers, which, from the darkness of the night, were almost the only objects we could see ; the vessel was then heaved down by the stress of the wind, her gunnel to the water ; but as we soon found she answered her helm, we concluded she was making way." It was four days before the party—short of provisions—got back to land. They had, before a favouring shift of the wind occurred at the last moment, decided on the hazardous course of trying to make the Scilly Islands without a chart to guide them, and, as Smeaton remarks, " Our friends were not without great reason alarmed concerning us." I have quoted this adventure of Smeaton's at length because it illustrates in a striking way one of the many risks that he had to run as engineer for the Eddystone.

The work of construction necessitated Smeaton's constant attention, for, in addition to the intrinsic difficulties, there were minor matters requiring his intervention. As regards a portion of the stone, for instance, the stonemason refused to deliver on the ground that the masters of three different vessels were unwilling to undertake the work because of the excessive size of the stones, and Smeaton had to send his own men and a boat to bring the stone. Then, again, he had to conduct his own series of experiments to find a satisfactory cement.

On another occasion when they were raising the moor-

ing chains of their relief vessel, and there was a danger of the chain breaking loose and the man who was handling it being cut in two, Smeaton himself undertook the dangerous task, as he comments: "This being the sense of my shipmates, and as I always made it a rule not to put another upon doing what I was to do myself, the *post of honour* naturally devolved on me." Smeaton mentions it as a matter of course, but as a great hindrance, that his boats were frequently stopped and boarded by the men-of-war's cutters to impress the seamen. Notwithstanding they were furnished with Admiralty protection, this was ignored by some of the officers, and it was continually necessary for him to approach the Commander-in-Chief and secure their release. He tried to get out of the difficulty by having the figure of a lighthouse painted on the mainsails of his boats. This, he found, served to protect the men while at sea, but left them still liable to arrest on land, and so he hit on the idea of giving each man a specially cut silver medal which he could produce to the press-gangs as evidence of the service on which he was employed. Another trouble was that the French privateers began to show activity, and the supplies of stone were consequently interrupted, and lastly a few of the workmen, though getting special pay in view of the danger and difficulty of their task, began to be mutinous and had to be dismissed.

By the 10th of June, 1757, shears and windlass had been fixed in position on the reef, the relief boat was safely at her moorings off the reef, and everything ready for laying the foundations. The first stone, weighing $2\frac{1}{4}$ tons, was duly laid during the morning slack of Sunday, June 12th, but the rise of the tide interrupting before the work was

finished, it had to be shackled with chains. The weather continued favourable, and in the evening it was fitted, bedded in mortar, fastened with trenails to the reef, and so completely fixed, the mortar in this case, as throughout the whole of the work, being coated with plaster of Paris to protect it until it was fully set. The weather remained favourable, and by Monday night the first layer or course of the new lighthouse had been completed. On Tuesday five of the thirteen stones belonging to the second course were landed; one of them had been set and fixed, and two others had been placed in their grooves when a strong wind began to blow. Work was stopped at once, and everything had to be made as fast as possible in the short time available. The two stones that were in position were chained down, the two others chained together, strongly lashed to eye-bolts and tied also to the slide ladder. Meanwhile the tackle blocks, mortar buckets, loose materials and tools had to be loaded into the yawls that were tossing alongside, threatening to be stove in at any moment, and the setting triangle by which the stones were hoisted and lowered into their places had also to be lashed. It took an hour and a half's hard rowing to regain the relief ship, though this was only 200 fathoms away from where they had to start rowing. On this occasion it blew a hard gale, but without damage to the work; but when the same thing happened a day or two later, it was found that the slide ladder and five pieces of stone had been carried away. There was nothing for it but to hurry back to Plymouth, and set the men at work night and day again to cut stones of exact measurement to replace those that had been lost. This meant two days' delay, which, as it turned out, did

not matter, as the weather continued too rough for them to work upon the rock.

By August 11th, the first six courses, consisting of 123 pieces of stone, had been laid (sixty-one days having been taken to do it), and the work was consequently now flush with the rock, and a common base made on which the rest of the structure could be laid in regular courses.

It is necessary to have some experience of the force of moving water to appreciate its magnitude, and without experience one would believe that stones weighing over a ton would be immovable by the waves. This is not the case, however, and as the essence of the work is the secure fixing of the stones, it is of interest to note the means that were adopted. As I have already pointed out, the stones were dovetailed together, but, in addition, grooves were cut at the sides of the stones 3 inches broad and 1 inch deep and oak wedges prepared to fit into the grooves. So, when a complete course had been laid and the wedges driven home, the course could only move as a complete unit. There was a danger, however, that the sea might wash away the underlying mortar, however carefully protected by plaster of Paris, and sweep the lot into the sea. To avoid such a disaster occurring before the mortar had set sufficiently to prevent it, holes were bored through the external part of each of the stones. When the stones were in position the hole was continued into the stone below by borers, being made $\frac{1}{8}$ inch less in diameter and 8 inches or 9 inches deep. Trenails were prepared to fit them, carrying little wedges at their far ends. These trenails were then driven home, and as the wedges touched the bottoms of the holes they opened out the trenails, and

so made them hold with such firmness that the trenails themselves ($1\frac{3}{4}$ inches in diameter) would break in two more easily than be drawn out. The heads of the trenails in the same way were wedged cross and cross. Permanent strength was given to the union between the stones by running liquid mortar or grout into the joints.

Nor was this all. As I pointed out elsewhere, Smeaton's idea was to have the lighthouse as firm as a monolith. Consequently, instead of having the stones simply laid one upon another, and, therefore, dependent only on their weight and on the mortar to prevent them from shifting, holes 1 foot square and 6 inches deep were cut into the centre and edges of the course, and the stones dovetailed into one another, so that any blow of the sea acting horizontally could only move the course by exerting a force sufficient to fracture the pillars of solid rock. By the 29th of September the ninth course had been completed, and the work was stopped for the winter.

It would be wearisome were I to attempt to describe the later stages of the building, of the way in which strength was given to the upper portions of the lighthouse by fixing the stones together with iron cramps, of the slabs of Purbeck paving-stone used to cover the joints in the structure to ensure their remaining watertight, of Smeaton's narrow escapes, as when on one occasion he fell from the tower on to the reef below, and on another when he was poisoned by the fumes from the charcoal braziers used to melt the lead that was required. I will content myself with mentioning that the organisation he established was so perfect, that throughout the whole period occupied there was only one occasion on which

the work was brought to a standstill through the necessary material not being at hand, and on this occasion the delay was due to the fact that the missing stones had been swept away by the violence of the sea.

Much evidence might be quoted to show the extraordinary solidity of Smeaton's 70-feet lighthouse, with its forty-six courses. As Smeaton himself points out, the lighthouse was in reality stronger than the rock on which it rested. Thus he writes: "There being a great set about the rocks, with wind at S.W., I could, by resting steadily against the wall of the lantern, perceive a sensible motion from the action of the sea. This I did not wonder at, having felt a steeple sensibly move by the ringing of bells; but I was quite surprised to find that such heavy seas as now rolled over the *adjacent* rocks, *without touching* the building, produced a motion nearly as sensible. This, however, fully convinced me of what I had for some time been led to think, that the Eddystone rocks have a very sensible degree of elasticity."

Again, in 1762, after the lighthouse had been steadily in use since October 16th, 1759, Dr. Mudge, who sent Smeaton a report on how the building had stood through a tempest so terrible that it has been said, "If the Eddystone lighthouse is now standing, it will stand to the Day of Judgment," wrote in a postscript: "I broke open this letter to mention a whimsical circumstance that comes in my head: One of the articles (besides sugar, some flour, etc., which they landed at the house) was a gallipot of putty, to repair, as I said, the only derangement the house had suffered."

Smeaton's lighthouse stood from 1759 to 1882, but in

the late 'seventies of last century the reports from the lighthouse keepers caused serious anxiety as to the stability of the building. An investigation was made by Mr. Douglas, the engineer of the Trinity House, and others, and it was found that, while the tower itself showed no signs of decay, the rock on which it stood was being undermined by the action of the waves. The Trinity House resolved on building another lighthouse in its place, but at the time there was one of those ill-informed popular demands that the Eddystone reef itself should instead be destroyed by blasting. The Eddystone light is, in fact, most valuable, not only as a leading light for ships entering Plymouth, but as a guide to ships for determining position, and as a link in the chain of lights by which the Channel is navigated.

I will not describe in detail the construction of the new house. It was decided to make it taller, so that its light might be visible from a greater distance, and to facilitate the work a coffer dam was built on the site selected. Like his great predecessor, Smeaton, Douglas decided not to use any blasting process in case he might thereby weaken the foundations, but he had the great advantage of being served by steam tenders and of being able to use powerful rock drills driven by compressed air to excavate the rock. One of the precautions that he had to take was to set men to watch for the onset of rollers and warn the men at their work. When such a warning was given it was too late to try to get out of the way, but the men, who all wore lifebelts, used to hold on to the iron stanchions as the waves broke over them, taking care at the same time that their tools were not swept away. The first landing on the

rock was made in February, 1879, and the work was completed in the June of 1881. Whereas Smeaton's tower contained 988 tons of stone, the present one contains 4,668, and nine rooms, as compared with four (excluding the lantern) of the previous building. It is 130 feet high, or nearly double the height of the former.

I have written at some length of the Eddystone lighthouse, partly because it is one of the best known of the lighthouses, and partly because its construction illustrated several of the chief difficulties against which lighthouse engineers have to contend. Lest you should think that these difficulties are unique, I will give a few details now of the building constructed by the author of the classic work on lighthouse construction, Alan Stevenson, for it shows that in this case, too, the risks were similar, if not greater, and the service rendered to seamen commensurate with the danger of erecting the building.

The Skerryvore rocks, lying off Argyllshire, from time immemorial have been a terror to seamen, a confessedly incomplete list enumerating the number of vessels lost on them in the forty years before 1844 as thirty, and, as Stevenson's account of his experiences in the early stages of the construction are so vivid, and as there is so great an advantage in reading the account of the man who was actually in charge of the operations, I will quote the words as he wrote them. "The operations at Skerryvore," he writes in his book on "The History, Construction and Illumination of Lighthouses," "were commenced in the summer of 1838, by placing on the rock a wooden barrack, similar to that used by Mr. Robert Stevenson at the Bell Rock. The framework was erected in the course of a season

on a part of the rock as far removed as possible from the proposed foundations of the lighthouse tower; but in the great gale which occurred on the night of the 3rd November following it was entirely destroyed and swept from the rock, nothing remaining to point out its site but a few broken and twisted iron stanchions, and attached to one of them a piece of a beam so shaken and rent by dashing against the rock as literally to resemble a bunch of laths. Thus did one night obliterate the traces of a season's toil, and blast the hopes which the workmen fondly cherished of a stable dwelling on the rock, and of refuge from the miseries of sea-sickness which the experience of the season had taught many of them to dread more than death itself. After the removal of the roughest part of the foundations of the tower had been nearly completed, during almost two entire seasons by the party of men who lived on board the vessel while she lay moored off the rock, a second and successful attempt was made to place a second beacon of the same description, but strengthened by a few additional iron ties, and a central post in a part of the rock less exposed to the break of the heaviest waves than the site of the first barrack had been. This second house braved the storm for several years after the works were finished, when it was taken down and moved from the rock to prevent any injury from its sudden destruction by the waves. Perched 40 feet above the wave-beaten rock in this singular abode, the writer of this little volume, with a goodly company of thirty men, has spent many a weary day and night at those times when the sea prevented anyone going down to the rock, anxiously looking for supplies from the shore, and earnestly longing for a change of the weather

favourable to the recommencement of the works. For miles around nothing could be seen but white foaming breakers, and nothing heard but howling winds and lashing waves. At such seasons much of our time was spent in bed, for there alone we had effectual shelter from the winds and the spray which searched every cranny in the walls of the barrack. Our slumbers, too, were at times fearfully interrupted by the sudden pouring of the sea over the roof, the rocking of the house on its pillars, and the spurting of water through the seams of the doors and windows, symptoms which to one suddenly aroused from sound sleep recalled the appalling fate of the former barrack, which had been engulfed in the foam not 20 yards from our dwelling, and for a moment seemed to summon us to a similar fate. On two occasions in particular these sensations were so vivid as to cause almost everyone to spring out of bed; and some of the men fled from the barrack by a temporary gangway to the more stable, but less comfortable, shelter afforded by the bare wall of the lighthouse tower, then unfinished, where they spent the remainder of the night in the darkness and the cold."

The Skerryvore lighthouse was duly completed, thanks to the heroism of the builders, but from the Eddystone and the Skerryvore we will pass to a part of the foreshore of England with which many of you may be personally familiar. As you sail down the waters of the Thames estuary you pass a succession of slender-looking screw lighthouses that stand upon piles. These are built upon the sandbanks that stretch far out towards the North Sea. The seaweed clings to their straddling supports, and, gaunt and weather-beaten, they point out with their sector beams of red light

the dangers that the ships on their passage to and from the London river have got to avoid. The Maplin is the lighthouse I have specially in my mind, a conspicuous object that one always strains one's eyes to pick up. The advantage of the pile lighthouse is that the legs of the structure offer little or no resistance to the tides or storms, and the waves pass harmlessly beneath the lantern and the rooms in which the keepers live. The Maplin—the others are known as the Chapman, the Mucking, and the Gunfleet—had the eight hollow piles on which it rests forced into the sands, but the other lighthouses were built on screw-piles. In these the piles are of solid wrought iron, 5 inches in diameter, the base being furnished with a screw as much as 4 feet in diameter, and a drill-shaped head. These lighthouses, it must be remembered, stand in shallow water, and though an ugly sea can get up round them, they do not have to meet the shock of the seas driven across the deep ocean.

The approaches, too, of the Thames are guarded with lightships: the Mouse, with its distinctive green light, and the Nore, the oldest of such vessels, with its bright white light, and a dozen or more of others. These have had in their construction the best thought that the naval architects could give them, for it is a question of construction largely as to whether those vessels behave well in a seaway, or pitch and toss so as to give continual discomfort to their crews. Living on a lightship makes incessant demands on the judgment and vigilance of the master, not only as regards the light for which he is responsible, but also as regards the length of mooring chain that he has to let out according to the weather. The movement of the boats is

peculiar, and such that it is no uncommon thing for seamen when they first take up their duties to find themselves as sea-sick as the novice when first he goes to sea.

There are the buoys, too, the lighted and the unlighted buoys that mark the shoals with which the estuary is beset. An amazing amount of scientific knowledge and ingenuity has gone to the construction of these, as it has in even greater measure to the construction of lighthouses. Thoroughly perfected mechanism has been devised, so that each light should give its own special rhythmical flash; elaborate tests have been made to ensure that the best type of oil or gas has been selected for the work. In places electricity has been pressed into service. The optician has been called in to bring to bear his special knowledge with a view to providing the most satisfactory types of lenses, and expert advice has had to be taken, too, as to the best position for fixing the site of the lighthouses. It by no means follows that the higher the lighthouse the more suitable it will be for its purpose. Take, for instance, the case of the lighthouses on Beachy Head. The original lighthouse was placed high up on the top of the cliff, but experience showed that when fog swept up the Channel the light became invisible at sea, whereas by establishing a lighthouse lower down at the cliff foot, a far greater visibility has in such conditions been obtained. All sorts of ingenious devices have been coupled with the work of the lighthouse engineer. A device has been recently installed whereby in times of fog signals should be sent out below the surface of the sea to ships by means of special receivers dipping below the waters and picking up the waves of sound.

Photo: J. Weston & Son, Eastbourne

BUILDING BEACHY HEAD LIGHTHOUSE

These are matters, however, rather for the inventor than for the engineer. The point he has incessantly to bear in mind is that each piece of work he is asked to undertake will have its own special difficulties that he will be called upon to overcome, often without precedent to guide him. There are, however, three factors particularly that guide him: form, weight, and rigidity. The form of the lighthouse designed to bear the greatest strain should not, as was at one time supposed, approximate as much as possible to the tree trunk, but it should consist of a number of conic sections placed one upon the top of the other. A low centre of gravity is obtained and the strength is greater at the part where it is most needed to meet the force of the waves—the base. As regards the question of weight, the principle followed is to make the structure as heavy as possible, so that its own inertia may make it impossible for it to be moved. And lastly, as we have seen in studying the lines of construction followed by Smeaton with the Eddystone lighthouse, the building should be as far as possible a monolith. Stone should be jointed to stone, and the whole firmly jointed to the rock, so that each part of the building is an integral and immovable part of the whole.

To no class of engineer do we owe a greater debt of gratitude than we do to the lighthouse engineer. He has to do his work in conditions of serious danger and acute discomfort, and his chief source of satisfaction in the accomplishment of the good work he does must be in the feeling that, as a result of his efforts, the safety of life at sea has been enormously increased.

CHAPTER XX

RAILWAYS—AERIAL RAILWAYS—SWINGING RAILWAYS AND MONO-RAILS

In the year 1819, at a time when the celebrated Duke of Bridgewater had covered England with a network of canals, a friend is said to have remarked to him: "You must be making handsomely out of your canals?" "Oh, yes," was the Duke's reply, "they will probably last my time, but I don't like the look of these trainroads; there's mischief in them!"

It is, when you come to think of it, extraordinary that great ideas, though they have seemed to float about vaguely at various periods in the world's history, are seized upon and crystallised in the brain of one or two individuals, who give them the driving force necessary to transfer them from the realm of fancy into the domain of fact. It needed a Homer to fix the floating poetry that the world has wondered at in the Iliad and Odyssey; Athens had to wait for a Solon to crystallise her laws, just as Sparta had to wait for a Lycurgus; the Stuarts had stirred up the ideas of revolution in men's minds for many years, but England waited for a Hampden and a Cromwell to kindle the tinder of revolt; the world had long dreamed of an outlet to the West, but the centuries dragged on their weary course till the enterprise of Columbus shot out and discovered America. Instances could be multiplied inde-

finitely, but I think it is not generally known that we owe the idea of the locomotive engine as a means of passenger transport to Thomas Gray, who proved himself on this subject to be the necessary man of the one idea.

Gray, in 1819, was travelling in the North of England and found himself watching a great train of coal wagons being pushed along a tramroad that connected one of the collieries of the district with the wharf at which the coals were delivered. "Why," he suddenly asked the engineer in charge, "are not these tramlines laid down all over England, so as to supersede our common roads, and steam-engines employed to convey goods and passengers along them so as to supersede horse-power?" The engineer smiled at his question: "Just you propose that to the nation, sir, and see what you'll get by it. Why, sir, you'd be worried to death for your pains!" But the idea had captured Gray. He gave his friends no peace, he attacked the public with letters and circulars and pamphlets, and at last he wrote a book which was published in 1820, with the lengthy title: "Observations on a General Iron Railway, or Land Steam Conveyance, to supersede the necessity of horses in all public vehicles, showing its past superiority in every respect over all the present pitiful methods of conveyance by turnpike roads, canals and coasting traders, containing every information relative to railroads and locomotive engines, by Thomas Gray."

The book attracted attention, and within four or five years Gray's idea had captured the public, and people were asking what had been the good of writing a big book to explain what any fool had known all along. It is a natural attitude of mind, and when discoveries are an-

nounced to-day, you will find that it is quite a common criticism for eminent people to go even farther and to say, "There's nothing in it, and, anyway, if there were anything in it, I discovered it myself long ago."

In giving this credit to Gray, it is only fair to note that though it was he who put the idea before the public, it was George Stephenson who had originated it by his construction of the first locomotive engine, which ran its first trial in 1814.

In this book we are concerned with the present rather than with the historical side of engineering, and as railways have formed the subject-matter of a special volume of this series, I shall mention only a few of the more curious developments of railway engineering, leaving you to refer back to Mr. Hartnell's book for an account of railway engineering as a whole, and of the great lines such as the Trans-Continental Railway of Australia, the Cape-to-Cairo Railway in Africa, or the vast Trans-Siberian Railway that has been constructed by Russia.

The aerial railway is, I suppose, the most extraordinary modification of transport that has as yet been made. It has forced its way to all parts of the world, and we find it carrying sugar-cane in Jamaica, iron-ore in Bilbao, heavy timber in the Apennines, and passengers in Cape Town. Naturally enough, it assumes various forms. In some it consists of an endless rope supported on spans, continually on the move, and carrying baskets or cars slung on to it. In others, the wires themselves are stationary, and the cars are dragged along the wires as if they were rails by means of a rope; and, lastly, of course, the motive power may be gravity alone, as at Gibraltar, where the object

of the aerial railway is to transport material from the higher to the lower level. It is at Bilbao that this type of railway reaches its greatest development. The main route has 9 miles of wire running side by side, and in the district altogether there is as much as 30 miles of it, about 120,000 tons of iron ore being thereby carried with it annually. At Cape Town it has been adapted both for goods and passengers. The wires were originally designed to carry materials to the waterworks on the Table Mountain, a distance of 5,280 feet, with a rise of 2,168 feet. At places the wire becomes almost perpendicular, and the first of the long spans, which is as much as 1,470 feet, lifts the level from 698 feet to 1,480 feet.

Are these aerial railways dangerous? I don't think that charge could fairly be brought against them when you consider the huge strain that properly-made wire ropes will support. Here is an example taken, it is true, from tramcar work, which, after all, is similar. In Melbourne the cable is 19,500 feet long, $3\frac{5}{8}$ inches in circumference, and weighs 20 tons to the piece. After being 94 weeks and 3 days in use, during which period it had run 120,108 miles, it was put on to a lighter line, where it increased its total mileage to 148,726 miles. By this time it was appreciably lighter, but had lost little of its toughness or strength. A similar example of the toughness of wire rope can be taken from one of the aerial railways, where a single cable in a period of two years had carried 165,000 tons. At the outset it had a breaking strain of $29\frac{1}{20}$ tons, but when it was taken off on the ground that it had had sufficient wear, its breaking strain was found to be as much as $27\frac{1}{2}$ tons.

The railway that is slung on rails is another type having its own special advantages. It is really a German idea, and they speak of it as the *Schwebebahn*, or swinging railway. The projector of the type was a Mr. Langer, of Cologne, who died before seeing his idea take material shape. A good example of it is to be found in the railway that runs from Vohwinkel through Elberfeld to Bannen. As might be expected, the motive power for this peculiar type is electricity. The rails—there are two of them, to allow carriages or trains to travel in either direction—are supported on A-shaped trestles that lift them well above the level of the ground. The great advantages of the suspended railway are its cheapness—it only costs a few thousand pounds a mile to build—and the handiness with which it can be made to cross viaducts, crowded streets, difficult curves and rugged hill-sides. The ordinary practice is to run isolated carriages along the lines, or small trains of two or three carriages, taking them, if necessary, all the length of a river bed in order to save the cost of valuable ground.

You have read by now in the chapter on the Gyrostat a reference to the remarkable achievements of Mr. Louis Brennan with his mono-rail. Mr. Brennan's, however, is not the only scheme for a mono-rail railway, and the proposals of Mr. F. B. Behr, which have got beyond the experimental stage, are so remarkable as to deserve at least a mention in this volume. Curiously enough, he got his first idea from the ingenuity of a French engineer, who found himself face to face in Algeria with the difficulty that his lines were always being submerged by sand storms that swept over the plains. Watching a caravan of camels one day,

Photo: G. Wehrli, Kilchberg

A RACK RAILWAY ON MOUNT PILATUS

the idea struck him that a line might be constructed where the principle of the balanced pannier might successfully be incorporated. The engineer lost no time in putting his idea to the trial, balancing his loads on an elevated rail, and his plans proved a conspicuous success. Mr. Behr, hearing of the scheme, at once decided to adopt it for passenger traffic, and he succeeded in constructing a satisfactory passenger line in Ireland, where the entire train balances on a single rail with two supporting rails on either side, being perched on its rail as securely as the pannier bags are slung across the backbone of a mule. Mr. Behr has since proved that his railway is something much more than a toy, for he succeeded at the Brussels Exhibition in constructing a 3 mile long track, on which his train travelled at the astonishing speed of 90 miles an hour.

Ninety miles an hour, however, is far from being a record speed, for in the special electric trains used in the speed tests for the Society for the Study of Electric Express Railways of Berlin, the astonishing speed of 118 miles an hour was attained on the experimental line between Marienfeld and Zossen. During the last few years, amazing speeds have been achieved, and still more astounding speeds have been projected. It is nothing astonishing, for instance, to read of the promotion of railway lines on which the speed of 200 miles an hour is to be reached.

Crude speeds are apt to convey no very definite idea to the imagination, and to indicate to you what these speeds mean, I am including here a table showing their value comparatively. The speed of a railway train travelling at 118 miles an hour can be put in the form that a mile

would be covered in about $30\frac{1}{2}$ seconds, and other record speeds are :

	Min.	Sec.
Racehorse	1	$33\frac{1}{5}$
Cyclist	1	38
Trotting horse	2	$2\frac{3}{4}$
Skating	3	0
Eight oar	3	49
Running	4	$12\frac{3}{4}$
Walking	6	23
Swimming	25	$13\frac{2}{5}$

If we look back at the development of the railways, we have, I think, every reason to look forward in the near future to a considerable increase in our prevailing rates of speed. The steam engine, one has to remember, is more or less limited, just as the flat bed printing press is limited because its backward and forward movement if unduly speeded up is liable to shake the machine to pieces ; but it is difficult to indicate a limit of speed for electrically-driven rotary movements. Electricity seems destined altogether to replace steam as a motor power for the railway train. It may be that in the time to come man will secure such a mastery over the air that for great speeds he will make use of aerial transport, but at present all the indications point rather to aerial transport supplementing rather than replacing the railroad, just as the railroad has supplemented rather than replaced water transport. Of this latter truth we have a striking example in the Manchester Ship Canal, an enterprise that by bringing Manchester to the sea has saved that city from being starved out by its rival Liverpool.

In the future the railway engineer will, I am convinced, never cease to hold a prominent place. In the past, he has been one of the factors making most prominently for the civilisation of the world, and when one considers the vast tracts of the world that still require to be linked up and brought into close touch with one another, it is impossible to doubt that the future lying before the railway engineer will prove even more glorious and distinguished than has been his past.

CHAPTER XXI

THE WORK OF A CONTRACTOR—CONSTRUCTION IN AFRICA, LONDON, CHILI, RUSSIA, AND NEW BRUNSWICK

IN the course of this book we have considered various special engineering works, but I think it might also interest you to hear some account of the work undertaken and in progress at one and the same time by an individual firm. For the purpose I have selected Messrs. Griffiths and Company, of Griffiths House, London Wall, partly, I must admit, because of the magnitude of the work that they are carrying through, but more especially because the head of the firm, Mr. Norton Griffiths, is a man who stands out pre-eminently for the importance of maintaining intact the great Empire that we control, and of furthering its interests by every means within his power. It is only recently that Mr. Griffiths' firm issued an official publication which gave full details of the work they were engaged on in various parts of the world. They pointed out then that among the more important works recently carried out by them, and in course of construction, were: the Benguella and Katanga Railway in Portuguese West Africa (£2,500,000), the Battersea to Deptford Sewer (£481,000), the Chili Longitudinal Railway (£4,026,000), the Baku Waterworks (£1,026,000), and the Harbour Works, St. John, New Brunswick. About each of these works an epic could be written, for in each case the operations have been of excep-

tional difficulty, and have been carried through with an energy and enterprise that mocks at the obstacles that Nature has strewn in the path.

To most of us the Benguella Railway is but a name and nothing more, but to the trader in South Africa it stands for a great deal more, for not only does it mean the running of a railway line from the West Coast of Africa eastwards into the interior, but it brings the West Coast directly into touch with the Cape-to-Cairo Railway, renders accessible the rich copper deposits round about Katanga, in Central Africa, and aims at bringing Pretoria and the Rand Gold Mines a few days' journey closer to London. The contractors have had a stupendous job to undertake. In Lobito Bay they have already built a permanent wharf with 8-feet cylinders filled with concrete and reinforced concrete and decking, and a branch line has had to be constructed to link up the main railway with the Cape-to-Cairo Railway. That the line is 800 miles long is, perhaps, hardly a matter for comment, but it has to be remembered that much of the material for it has had to be brought direct from England, that a 250-feet span bridge has had to be thrown across one river, while over another a bridge of nine spans, each of over 35 feet, has had to be thrown. When the line had only been carried 32 miles from the coast, it passed through a rocky gorge, where for 1½ miles it has a gradient of 1 in 16, and has to be worked on the rack system, and so it steadily rises until it gets up to the top of a lofty plateau. The country that it taps is essentially a white man's land, giving excellent farming facilities and offering at present unique opportunities for the big game hunter. Among the many difficulties that the contractor

has had to overcome have been the shortage of labour, to counter which a large number of Indian natives, trained in great Indian construction works, were imported, and the absence of water, to meet which special water stations were established, and in one instance, at least, a large well had to be sunk. The value of the work is perhaps most strikingly shown by the fact that when the line was only in its early stages in the first six months of 1907, it doubled the total tonnage of Lobito for the preceding year.

From the West Coast of Africa the scene changes to the heart of London, and the contractors who had been thinking in terms of tropical heat and traffic problems were called to turn their attention to a great underground sewer from Battersea, south of the river Thames, to Deptford. It was to be 9 miles long, to consist of 6 miles of cast-iron lined tunnel, passing through water-bearing strata, and of 3 miles of brick-lined tunnel, passing through clay. The cross-section of the tunnel made the building no light affair, for at its largest it is 9 feet 10 inches in diameter, or only a trifle less than most of the London Tube Railways, and to so great a degree of accuracy are the engineers expected to work, that while the error of a hundredth part of a degree would mean that the two ends of the tunnel, which are constructed from opposite sides to meet in the middle, were only out of truth by 2 feet, an approximation to within an error of a single inch is only looked upon as fairly good. In view of the description of tunnel-driving, to which I am devoting a special chapter, there is no reason for me to say more here than that the problems were similar, and that the sewer is destined to form a very important link in the drainage scheme of Greater London.

Mr. Norton Griffiths also obtained a great work in Chili, the construction of the Chili Longitudinal Railway. This, indeed, is a gigantic project, with an expenditure of over £4,000,000 involved, and a line of nearly 400 miles in length to construct. The railway runs north and south between Cabildo and Toledo, and is eventually to form part of a great pan-American Railway that is to run from New York to Valparaiso. Economically, for the present, its great value will be to give both to Bolivia and Chili an outlet for their agricultural products, and thereby to make the country less dependent than in the past on the nitrate industry, which hitherto has been the great factor in its financial condition. The capital importance of this can be gathered from the fact that till now the exportation of the nitrate products has been, in the absence of any impetus to agricultural production, the chief source of Chilian wealth. The more important centres of civilisation, forming the natural outlet for the consumption of agricultural products, have lain to the south out of communication with the agricultural districts, and from their isolation have in times of stress been brought more often than once to the verge of starvation. The new line, in fact, does the greatest of all economic services, as it effectually renders possible the unrestricted distribution of wealth. The following short table will give an idea of the vast scope of the undertaking:

Length of line	370 miles
Total length of tunnels ..	3 miles 3 furlongs
Length of bridges	2 miles 7 furlongs
Earth requiring to be moved..	14,000,000 cubic yards
Weight of rails	35,160 tons
Sleepers to be set	1,000,000

As in the case of the railway in West Africa, the difficulties of the country through which the line has had to be driven added enormously to the complexity of the task.

We next come to the water supply for the town of Baku, in Russia. In this case, again, the work is on a huge scale, for a water conduit 120 miles long has to be built. The sources of the supply are artesian wells in the hills, and the pressure is such that the water often rises 15 feet above the surface. The original supply is collected into a great measuring chamber before following the slope for a matter of 100 miles. It has then to dive beneath the Ata-chai River and the swampy ground around it, an obstruction that it succeeds in passing by means of a monster siphon 42 inches in diameter and no less than 10,000 metres in length. A little farther on a large pumping station is necessary, and then an 810-metre-long tunnel takes it through the mountains to a large reservoir, from which it is to be distributed to the town.

The last of the large works with which I have to deal is the contract for the construction of the New Harbour in Courtenay Bay, St. John, New Brunswick, involving an expenditure of some 13,000,000 dollars, and the construction of the largest dock on the North American continent, or indeed in the world, having a length of 1,150 feet.

The dock is, however, of only secondary importance to the rest of the work, which includes the building of a breakwater some 6,000 feet in length, the construction of quays and yards by reclamation of some 30 acres in extent, and the dredging of a channel and basin to a depth of

35 feet below low water, necessitating the removal of some 12,000,000 cubic yards of material, which is performed by three monster dredgers of the most modern type. This work is expected to occupy five years, and is the first contract of magnitude entered into by the Dominion Government.

I am afraid that this outline of the great works that have been in course of construction at one and the same time by a single firm may, for the moment, strike you as somewhat lacking in interest. I have given, however, only the bare lines of the undertakings with a view to emphasising the amazing complexity of work that the great contractor must be ready at once to undertake. Just consider what these projects mean in resource to Messrs. Griffiths and Co. They are expected to have expert knowledge of constructing mountain railways, to be familiar with the vastly different conditions obtaining in West Africa and in Chili, to be conversant with the labour market all over the world, to be bridge builders and tunnel drivers, to be thoroughly conversant with the methods of driving an underground tunnel through the water-bearing strata of the London subsoil, to have at their finger ends every detail of hydraulic engineering, and at the same time to be experts in the transportation of materials and in finance. Naturally this wide knowledge is only obtained by the firm being able to draw on a stock of highly trained experts, but the credit of it all belongs to the founder of the firm, Mr. Norton Griffiths, who, by his personality, his genius and enthusiasm, is able, in addition to his labour as a Member of Parliament, to weld all this talent together for the achievement of a particular object, and, by his

skill as an organiser and an engineer, of making it far more productive than it ever could be if it stood alone.

It is a splendid career for a man, this work of the contractor. Success in it demands the possession in a high degree of all the qualities that go to the making of a great leader—courage, imagination, energy, enterprise, resource, endurance, enthusiasm, judgment, organising ability, self-control, and the personal magnetism that is necessary for the management of men.

CHAPTER XXII

TUNNELLING—THE MONT CENIS TUNNEL, THE SIMPLON TUNNEL, THE SEVERN TUNNEL, THE THAMES TUNNEL, AND THE EAST RIVER GAS TUNNEL

TUNNELLING seems, on first thoughts, a simple enough operation, but it is only necessary for us to look round the animal creation to come to a realisation of its difficulty. Countless of the wild beasts, as one can see from the way in which they make their lairs in caves, have appreciated the idea of the tunnels affording a refuge from danger, but it is only the smallest of them that have found tunnel construction possible. The fact is not to be wondered at when you get to learn of the extraordinary difficulties that man has had to surmount in constructing his great tunnels. And yet, the necessity for the tunnel has been so great that it goes back to the earliest periods of man's history. It is a gruesome idea, but we know it to be true, that a Theban King on ascending the throne started at once on the excavation of the tunnel that was to lead to the sepulchre that was to form his final resting-place. Then we read of the tunnel driven under the Euphrates, the engineers hitting on the highly practical if elaborate plan of diverting the stream of the river, building their tunnel on the dry bed, and then returning its waters again to their ancient course. The Romans were tunnel builders on a mighty scale, but their achievements were bought

with the price of the blood of their slaves. We must give credit to them, however, for their skill and ingenuity, if not for their humanity. They hit on the idea of weakening the face of a solid rock by heating it, and of taking advantage of the chemical properties of vinegar to attack it, and Pliny tells of how in the excavation of the tunnel for the drainage of Lake Fucino 40 shafts and a number of inclined galleries were sunk along its length of 3½ miles, some of the shafts being as much as 400 feet deep. The Middle Ages added little to the knowledge of tunnelling gained by the Romans beyond the adaptation of gunpowder for the purposes of blasting, and the tunnelling of the Middle Ages was restricted almost entirely to the construction of underground escapes for the castles of the barons. The arrival of the steam railway was needed to force the attention of the engineers at all generally to the work. Accurate surveying instruments, highly specialised explosives, power-driven rock drills, were all pressed into service, and so far the culminating achievement of the art has been the invention by Sir Isambard Brunel of the shield that makes the forcing of a tunnel through soft, water-laden strata a comparatively simple task. The problems of the tunnel-builder are so varied, that I can do little more than select a few examples to illustrate the methods that the engineers are called upon to apply.

The Mont Cenis Tunnel, from the standpoint of construction, as being the first of the great Alpine tunnels, is the most marvellous in the world. Fifteen years (1857–72) went to its building, and as they were cutting through the 7.9 miles of its length, the engineers found themselves forced to invent many of the special appliances that have

Photo: Underwood & Underwood, New York

DRILLING HOLES IN THE SIDE WALL OF A TUNNEL

since become a part of the stock-in-trade of the tunnel engineers. Thus, it was in the Mont Cenis Tunnel that use was first made of power drills with compressed air to drive them, of aspirators to suck the foul air from the excavation, of air compressors, turbines and so forth.

One of the most difficult tasks in driving these long tunnels with the men at work simultaneously from both ends is to ensure the two tunnels meeting accurately in the centre. Elaborate surveys have to be made, and in the construction of the St. Gotthard Tunnel, which is the classical example of this type of work, the most accurate form of surveying known as triangulation, had to be employed. The St. Gotthard Tunnel is 9.25 miles long, and two different astronomers were employed to check each other's work, getting their centre line by making use of different sets of triangles, and by working at different times. Every angle was read four times, and for each reading special steps were taken to avoid the possibility of instrumental error, and the differences in the readings obtained were found to be less than the 324,000th of a right angle, or, as engineers would describe it, as less than a second of arc. From these readings it was expected that when the two ends of the tunnel met the deviation from the true centre would not be more than 2 inches. As a matter of fact, the deviation was as much as 11 inches, and though engineers profess to regard this as a large error, their discounting of the result is, to my mind, only a further proof of the amazing degree of accuracy to which we can attain by modern instruments.

To return to the Mont Cenis Tunnel. Until 1861 the excavation was carried on by hand labour. The method

adopted was to drill thirteen holes near the centre. Round these came a ring of sixteen holes; then eight holes between this and thirteen above formed the third round, while close to the floor eight more holes were bored for the fourth round, each of them being 3½ feet deep. The time required for boring the holes was between 6 and 8 hours. From 1½ to 2 hours were required for filling in the holes with explosives, and from 3 to 5 hours to get rid of the blasted rock, so that in 24 hours it was only possible to make two blasts at the front of the drift. I am giving a diagram of the sections in which the tunnel was built. The different portions were completed in the order of the numbers, No. 1 being the portion known as the drift.

The engineers were fortunate in having plenty of water-power available, and they were able to make use of a natural head of water to drive air into a special reservoir at an 80-feet pressure.

It will come, probably, as a surprise to you to hear that in transferring this water power to the drills as much as 27 per cent. was lost by the friction of the water in the pipes, etc.; 23½ per cent. of it went to work the valves of the compressors, and on ventilation, and only 49.4 per cent. of it was available to drive the drills. As you can imagine, the work was of so comprehensive a character that the most elaborate machinery and machine shops had to be erected in connection with it. It was even necessary for a gas factory to be built at each end for lighting purposes. For ventilation, it was found that the compressed air after passing through the drills was so contaminated with oil as to be useless for breathing, and a special turbine,

worked by a stream of 75 gallons of water a second, with a head of 60 feet, had to be installed to drive air to the workmen at the rock face.

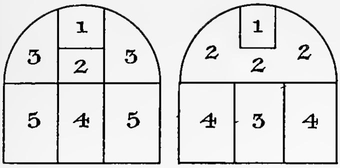
It was in connection with the Simplon Tunnel that the engineers found it necessary to take special care of the health of their workmen. Mr. Prelini has explained how great care was taken that the miners and men working in the tunnel should not suffer from the sudden change from the warm headings to the cold Alpine air outside, and how for this purpose a large building, at the time he wrote, was in course of erection, where they would be able to take off their damp working clothes, have a hot and cold douche, put on a warm, dry suit, and obtain refreshments at a moderate cost, before returning to their homes. Instead of each man having a locker in which to stow his clothes, a perfect forest of cords hung down from the wooden ceilings, 25 feet above floor-level, each cord passing over its own pulleys and down the wall to a numbered belaying pin. Each cord supported three hooks and a soap dish, which, when loaded with their owner's property were hauled up to the ceiling out of the way. There were 2,000 of these cords spaced 1 foot 6 inches apart, one to each man.

Paradoxical as it appears, tunnelling is comparatively easy so long as a passage has to be cut through solid rock, and though when one uses the word tunnel one thinks most naturally perhaps of the Mont Cenis, the Simplon, the St. Gotthard, or the Busk, it is the tunnels that have to pass through soft strata or through water and quicksands, which give the greatest anxiety to their constructors.

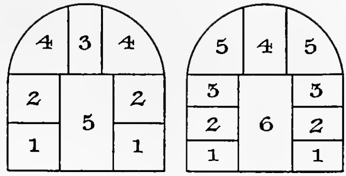
The difficulty of the tunnel driven through soft ground lies in the fact that the excavation has to be supported

by struts almost as fast as it is constructed. There is the danger that the material may cave in or slide, and, indeed, even when the masonry is in place, that the pressure may be such as to crush the keystone of the arch on which the tunnel depends. As I am fast outrunning the space available for this chapter, I am including a page of diagrams that must speak for themselves, and show some of the types of tunnel-making associated with the different nations. Passing over these types of construction, each of which has its own special advantages and drawbacks, we will come to a few instances of the most difficult types of tunnelling of all, submarine tunnelling.

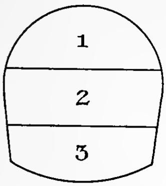
In submarine tunnelling it is usually the unexpected that happens, and in the Severn Tunnel the engineers were confronted again and again with the unexpected. The tunnel itself is 4 miles 642 yards long, and to expedite the work, and to facilitate pumping, several shafts had to be sunk. What the engineers did not allow for, however, was that their pumps would work badly, that a huge spring should be tapped while the works were in progress, that there should be a determined strike and a disastrous fire. To undertake the work at all showed courage on behalf of the engineers, for the railway company concerned had already spent seven years at it, and their workings were flooded before they decided to give out the contract. The contract was let by the engineer, Sir John Hawkshaw, to Mr. Thomas A. Walker, and I am fortunate in having by me the account he gave of the work. It is a story of incessant difficulties, of the pumps breaking at critical moments, of the fruitless heroism of the divers, of the misfortune that the irruption of a great spring formed, and of a foolish



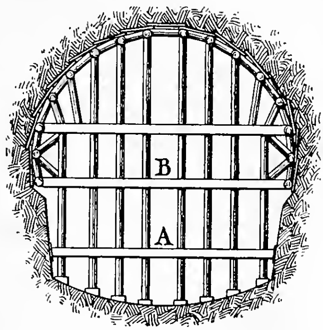
Sequence of excavations in the Belgian method



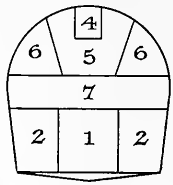
Sequence of excavations in the German method



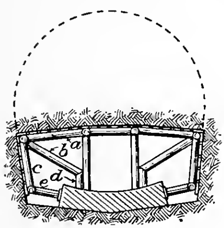
Sequence of excavations in the English method



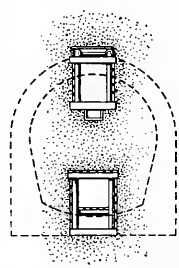
Construction of strutting English method



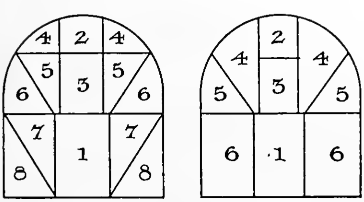
Sequence of excavations in the Italian method



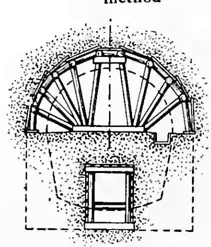
Italian method: Strutting for lower part



Preliminary drainage galleries, quicksand method



Sequence of excavations in the Austrian method



Construction of roof strutting, quicksand method

DIFFERENT METHODS OF TUNNELLING

With permission of the author from "Tunnelling," by Charles Prelini, C.E.: New York, D. Van Nostrand Company; London, Crosby Lockwood & Son

panic, which demonstrates clearly enough the way in which work such as this gets upon the nerves of the men engaged upon it.

The workings were flooded, and with the pumps going badly it was found impossible adequately to control the waters. The trouble lay in the fact that a valve in one of the doors had been left open, and that the door was 1,000 feet away from the bottom of the shaft. The diver, Lambert—I have often wondered whether he was related to the man of the same name whom I saw working on the wreck of the *Oceanic*—had made several plucky attempts to reach this door, and screw the valve home, and after his failure to reach the door on the 3rd November the engineers telegraphed for Fleuss to bring his patent dress and try if he could do the work. On the 4th he arrived, full of confidence in the success of his attempt. All the instructions which could be given to him were given, and on the 5th Lambert and he descended into the heading; Lambert with the ordinary dress and the air-hose to start Fleuss fairly up the heading, and to encourage him. After three attempts on the 5th November, it became evident that Fleuss had not sufficient practice as a diver or confidence in himself to go far up the heading; with some difficulty, Lambert was persuaded to put on Fleuss's dress, and try how he could work in it. After spending half-an-hour under water in this dress, Lambert returned fully satisfied, and undertook with a little more practice to make another attempt to get to the door, and he started to do so on the 8th. Knowing the obstacles he would have to meet on his way, it was not without considerable anxiety that the engineer and his men watched

Lambert start, for he had to climb over the skips, and other things in total darkness, and he was many times cautioned to be careful that the knapsack on which he depended for air should not strike the roof of the heading or any of the timbers, and fracture the small copper pipe which led air from his knapsack to his helmet. On the afternoon of the 8th Lambert succeeded in reaching the door. He pulled up one of the rails, and removed it, but having then been absent some time, and feeling, no doubt, nervous from the novelty of the experiment he was making, he returned again to the shaft without shutting the door. Still full of confidence, he started again on the 10th, and reached the door again in safety, went through, and let down the flap-valve, pulled up the other rail, and closed the door. He then screwed round the rod of the sluice-valve the number of turns he had been told it would take to shut it, and returned safely and in triumph to the shaft. Anxiously the engineers watched the floats which told them the level of the water, and their disappointment and annoyance was great when they found that it still continued to go down at the rate of only about 3 inches an hour.

Fresh pumps had to be ordered, and when at last the water had been got under control and a man could walk along the tunnel, the foreman of the Cornish pumps walked up the heading to the door, which the diver, Lambert, had shut, and then he found the cause of the disappointment felt at not gaining upon the water as soon as Lambert had succeeded in shutting the door. The rails were properly pulled up and removed, and the door was properly closed. The flap valve on the pipe on the south side of

the door was also shut, but the sluice valve on the other side had a left-handed screw, and the valve must have been closed when Lambert reached it ; and when he had given it the right number of turns to close the valve, instead of closing it, he had opened it to its full width.

As I have said above, the workings had been flooded by the irruption of a great spring when Mr. Walker took them over, and in 1883, when satisfactory progress had been made, this spring was one incessant source of difficulty and danger. The most terrifying experience of all, however, was when, as a result of a great tidal wave, the sea itself poured into the mouth of the tunnel, and imprisoned the workers, who, luckily, were able to make a hurried escape into the upper parts of the workings. A boat was sent to the men's rescue, but soon found its progress blocked by a heavy timber lying across its path, and a saw had to be fetched. This fell into the water, and the men had to wait anxiously until another was got, when eventually they were all rescued none the worse for their adventure.

As regards the panic, when the men thought the river had broken in upon them, though, as a matter of fact, the water seen was merely due to a drain being blocked, Mr. Walker writes : " One of them was seized with panic, and he called out : ' Escape for your lives, boys ! The river's in ! ' And the men had taken the alarm at once. As they ran towards the shaft, the men in the other break-ups joined in the panic, and at last the whole stream of men—300 or 400 in number—ran for their lives to the winding shaft at Sudbrook. When passing through lengths of finished tunnel, they spread out in a disorderly crowd, running perhaps 20 feet wide ; then they would come to a

short length between two break-ups, where there was only a 7-foot heading. Here they threw each other down, trampled upon each other, shouting and screaming; and then, to add to the disorder, the ponies in the various break-ups took the alarm and galloped down in the direction of the winding shaft, trampling on the prostrate bodies of the men."

It was with these and many other similar difficulties to contend against that the Severn Tunnel, after fourteen years spent in its construction, was opened to the public on December 1st, 1886.

Sir Isambard Brunel was the first engineer successfully to drive a tunnel beneath the surface of the Thames, and he succeeded in his object by the invention of the famous shield, which has since then been used in the construction of hundreds of tunnels throughout the world. The story goes that he got the idea of employing a shield to aid in the construction of tunnels through soft ground by watching ship-worms at work. Noticing that this animal had a head provided with a boring apparatus, and that its body threw off a secretion which made it impervious to water, he worked on a method by which its practice could be imitated, and at last, in 1818, he devised and patented the shield. Brunel's invention was a double one. In the first case, there was the iron cylinder, with an augur-like cutter attached to it in front, which was to turn and cut away the material in front of the cylinder, and so enable it to advance, the tunnel behind being lined continuously with iron-plating and masonry. This really contained the inventor's idea, but the machine that was used in the Thames Tunnel, and that has been the prototype of countless

other machines, consisted really of a group of separate cells which could be advanced one or more at a time or all together. It was decided that the sides of the cells should have friction rollers, and that the preferable motive-power for advancing the cells was hydraulic jacks. Brunel was selected as engineer for the first Thames Tunnel—a previous company had attempted the task and failed—and by means of his shield the task was successfully achieved, though the river twice broke in from above, and the inrush had to be checked by throwing clay bags from above into the holes as they developed, covering them with tarpaulin, and discharging a load of gravel on the top. The work was able to progress at the rate of 2 feet every 24 hours, and was completed in 1843, 20 years after the job was commenced.

If a list were published of remarkable tunnels, the East River Gas Tunnel, running from Long Island City to New York, would come high up in the list. As an engineering feat its construction is notable, because of the success with which a shield was driven from hard into soft strata, and then again emerged successfully into hard rock. From the human standpoint, it is an amazing feat of endurance, for there would have been plenty of excuse for the engineers if on any one of several occasions they had given up the job in despair.

At the outset the matter seemed simple enough. The result of various borings was to indicate that the tunnel would pass through solid rock, and the contractors, who entered into the contract in June, 1891, started on their work cheerfully enough. After tunnelling had gone on for some time, the rock on the New York side began to soften,

for a layer of decomposed rock substance was met with lying right across their path, ready as soon as it was disturbed to crumble away into slime under the action of the water.

To avoid this difficulty, the engineers tried to alter the direction of the tunnel, but their attempts were of no avail; a heavy bulkhead had hurriedly to be fixed, and then the contractors marked time to consider what had better be done. Eventually it was agreed to abandon the old heading, to sink the shaft 150 feet deeper, and to try again, this time making use of compressed air. The engineers started with a pressure of 35 pounds, but when they reached the treacherous fissure they had already touched, the mud and slime and water began to pour in, and they had to raise it and have the work carried on under a pressure of 45 pounds before they were able to hold it in check. At last they got through to solid rock, but not unnaturally they began to be anxious as to what would happen if the tunnel for the Long Island side struck the same decomposed vein. The vein was struck, and while the contractors realised the difficulties of the position they decided to continue blasting, though, as a precaution, they built up a stout bulkhead about 40 yards behind the head of the tunnel. When the charges exploded, an inrush of many yards of sludgy material took place, the flow being only stopped by rock fragments falling in, and closing the opening. The contractors now made every effort, but found it impossible to control the rush, and the heading was eventually abandoned when it had a steady 4-foot stream of water flowing through it.

Meanwhile, a dispute arose between the company and

the contractors, and the courts handed the unfinished work over to the company. After various delays and difficulties, the company decided that the only practicable method of completing the tunnel was to introduce a shield and to attempt to complete the work with the aid of compressed air. It required to be specially constructed, so that when it might have to be passed from hard to soft material, as from soft to hard, it could be erected or taken apart with the minimum amount of time and labour. To drive the shield, twelve 5-inch hydraulic jacks were used, and these were able to give a working pressure of 5,000 pounds per square inch, or as much as 700 tons on the whole shield. I want now to quote from the account written by Mr. Prelini, who was in charge of the compressed-air plant. He writes: "The shield was now advanced until it was necessary to disturb the bulkhead, the remaining bench ahead of the shield being blasted out as the shield progressed. The most difficult part of the work was now reached, for at the point where the shield entered the soft, black mud on top, there still remained about 12 feet of hard rock in the bottom, as the dip of this vein was over 40 degrees towards Long Island. Blasting had, therefore, to be continued in the bottom pockets of the shield after the top had entered the much-softened material. As soon as the bulkhead was passed, it was with great difficulty that the bottom could be kept clear of the black slush from overhead. The material had become so softened along the rock face that it was almost impossible to confine it, and several rushes of inflowing water occurred, until finally an open connection with the river was established, and the tunnel was visited by crabs and mussels, together with boulders, old boots

and shoes, brick and tinware direct from the river bottom. Notwithstanding these adverse circumstances the work was still progressing, although in 45 pounds of compressed air, which was now escaping through the heading, and causing a very violent ebullition on the river surface. The upward current of air held in check the downward current of water, so that no efforts were made to prevent its escape. On December 13th the shield finally cleared the rock, and was now fully entered into the soft, black mud. The main difficulty was now surmounted, the work progressed more rapidly, and the shield soon reached undisturbed material, which was found quite dry and hard."

All these unexpected delays naturally caused great anxiety and loss to the company concerned, and in order to hold out an inducement to the men to give their best work the company offered the foremen a bonus for work done, with the result that in one week, ending June 27th, a total of 196 feet of tunnel was driven, a pretty creditable record when you consider the conditions. On October 15th, 1894, gas through this tunnel was delivered to New York City.

I have only had space to refer to a few of the famous tunnels of the world, and I have by no means exhausted the methods adopted for their construction. I must content myself, however, with a bare reference to the ingenious method that is adopted at times when the ground is so soft that even with the shield and compressed air the work proves impracticable, whereby the sections of the proposed tunnel have been brought to the site in ships, lowered over the ship's side, and then guided by the divers beneath to be bolted home, and to find a resting place in

the sea bottom. In conclusion, I would ask you to remember that the tunnel engineer has even more than his fair share of anxiety and risk, and that, like the bridge-builder, he has continually to be on the alert, with the haunting knowledge that the forces of Nature which he is trying to combat may, after all, get the upper hand, and in an hour rob him of the fruits of a year's, or of several years', labour.

CHAPTER XXIII

SHIPBUILDING—THE YARDS—QUESTION OF POWER AND SAFETY

HAS it ever struck you, I wonder, what a fortunate thing it is for Great Britain that that great ditch, which we call the Channel, separates us from the Continent, and that, by a curious chance of modern history, we find ourselves the centre of the world? We can spare time, perhaps, just to glance over the world's history, the more so as it will be possible for me to place it before you in a matter of two pages. There can be no doubt, I think, but that in prehistoric time the cradle of the world lay in the East, and that the Eastern civilisations swept over Europe like a flood sweeps over low-lying ground, pouring down the valleys which, in this case—ethnically—corresponded to Asia Minor, Greece and Italy. Greece and Italy both had their period of development, prosperity and ultimate decay, until at last, by a curious irony of fate, the centre of the world's civilisation moved backwards to the East, to establish itself at Constantinople. Consider a map of the old world, with Constantinople as the centre. England, we see at once, lies in a position of no importance, and during the centuries that she lay thus neglected and of no consequence, the heptarchy, as we remember reading of it, became a single monarchy, and the nation, isolated as she was, free to work out her own development, constituted

herself a unit, if one of the least of the units, in the concert of the powers.

Fourteen hundred and fifty-three is the critical date of European history, for it was in that year that the Mohammedan hordes, sweeping over Western Asia, overwhelmed Constantinople in their all-conquering rush, and shattered the whole of the Eastern civilisation of Europe. Never, I should imagine, has there been such a catastrophe in the world's history, the heart of a great civilisation being ruthlessly destroyed, while the limbs—the great Italian city states, for instance—retained their vigour to the full. But they found themselves with their outlet to the East gone from them, as it seemed, for ever, and were forced to look to the West for fresh opportunities. The discovery of America is the logical outcome of the fall of Constantinople. Now, let us take a map of the world—the Navy League map would suit us the best—and see the astonishing change that the fall of Constantinople and the discovery of America has made in our fortunes. Before, as we remember, England lay out in the cold on the circumference of the world; but now, with America known to Europe, England becomes the centre of the globe, the port of call between the old world and the new, with the chance of a limitless development thrown to her by Nature.

This is no fanciful picture that I am putting before you. It was, as you know, at the close of the fifteenth century that America was discovered, and the sixteenth saw the period of our great merchant adventurers when, under Queen Elizabeth, England aspired to and won the position of mistress of the seas.

If you have had patience to follow me so far, you will

see now why it is that England—I use England and include Scotland, and with Messrs. Harland and Wolff at Belfast, Ireland as well—was forced to come to the front as a great shipbuilding power. The whole subject of ships has been treated already in this series, and as I want to avoid repeating what you have probably already read, I shall only deal in the shortest possible way with the actual work of construction, and then try and suggest to you a few of the developments that seem probable in the future.

What a marvellous place a shipbuilding yard is, with its monster cranes, some of them working as cantilevers, others as gantry cranes, all able to deposit their burdens with precision in the exact place that the workmen down below require it! It is a far cry indeed from the quiet of the architect's office, where every feature of the ship has been designed in its minutest detail, to the noise and clangour of the yards, where the ideas of the architect are materialising in solid steel. Man has to fashion his work in a vastly different way from Nature. First, he lays down the keelson, or the backbone of the ship, on the keel blocks. Out from it spring the naked ribs, then the transverse pieces to give it strength, and on the skeleton thus laid down must be moulded and riveted the plates that we can look on as the flesh of the completed liner or battleship. The shipbuilding yard of to-day is a very different place from the shipbuilding yard of a century since. Can you believe, can you realise, that we have only had steamships for a hundred years, and that we had had steam quite a long while before we thought of building vessels of steel? In less than a hundred years all this vast development has taken place.

Every device of the steel trade is pressed into service by the shipbuilder. We can stand and watch the plates of the liner come red-hot from the furnace, and see them crushed and beaten into shape. It is long since it has been necessary to drive the rivets by hand. There are special pneumatic tools to force them home through the rivet holes that the punching machine has made at the rate of fifty a minute. If a part of the complex whole which goes to make the ship does not exactly fit, there are machines to seize it as it comes glowing from the furnace to pass it on to other machines that will eat out the piece that has been supplied by the makers in excess. On all portions of the ship men of all conceivable trades are at work at one and the same time, and an impressive sight it is to stand amidst the forest of scaffolding seeing the ship steadily take shape as one watches her progress.

As you have learnt from "All About Ships," though, the mechanical skill of the shipyard is, perhaps, not the most wonderful part about shipbuilding after all. What of the brain of the man who can visualise the complete vessel before the first portion of her keel has been laid, who can plan out everything down to the smallest bolt, calculating exactly what strain each portion of the ship will have to bear; or of those who take the small size drawings of the designer and, using the floor of a room as their blackboard, chalk out in full scale drawings all the girders and plates and rivets that the vessel will eventually incorporate? In the modern building yard, it is a costly matter if a mistake is made; if the material ordered is too large, it means time and money to cut it down to shape, and waste, too, for the parts cut off have merely their value

in scrap metal. And if any of the parts prove too small, the matter is more serious still, for the absence of a part may easily mean a delay that postpones the completion of the whole ship.

A vast quantity of work requires to be done even when a vessel has been successfully launched from the slips. As such, she is a mere shell, and has to have her engines, her boilers and her maze of different fittings brought together before she can go and take her trials. An anxious job the trials are for the builders and the designer. Suppose a mistake has been made, just imagine, as Jules Verne did in the story of the man who was going to shift the axis of the earth, that a nought has been dropped in the course of the calculations, and that the new ship fails to make good according to her contract. This is—to the credit of our builders and designers be it said—a thing that very seldom happens, which is remarkable enough when you bear in mind that the power required to drive a vessel a certain speed varies almost as the square of that speed. In other words, to put the matter in the terms of horse-power, we can say that 400 horses can pull a vessel at a speed of 20 knots; it would require 441 horses to go 21 knots, 484 horses to go 22 knots, 529 horses to go 23 knots, and so forth. Consequently, when you are dealing with high-speed vessels, as you can imagine, it will require a vast increase of power to get out of them an additional knot of speed that may have been dropped by the builders or designers.

The progress of shipbuilding has been stupendous indeed. Each year sees the record of the previous year surpassed, and as the illustration I am printing shows

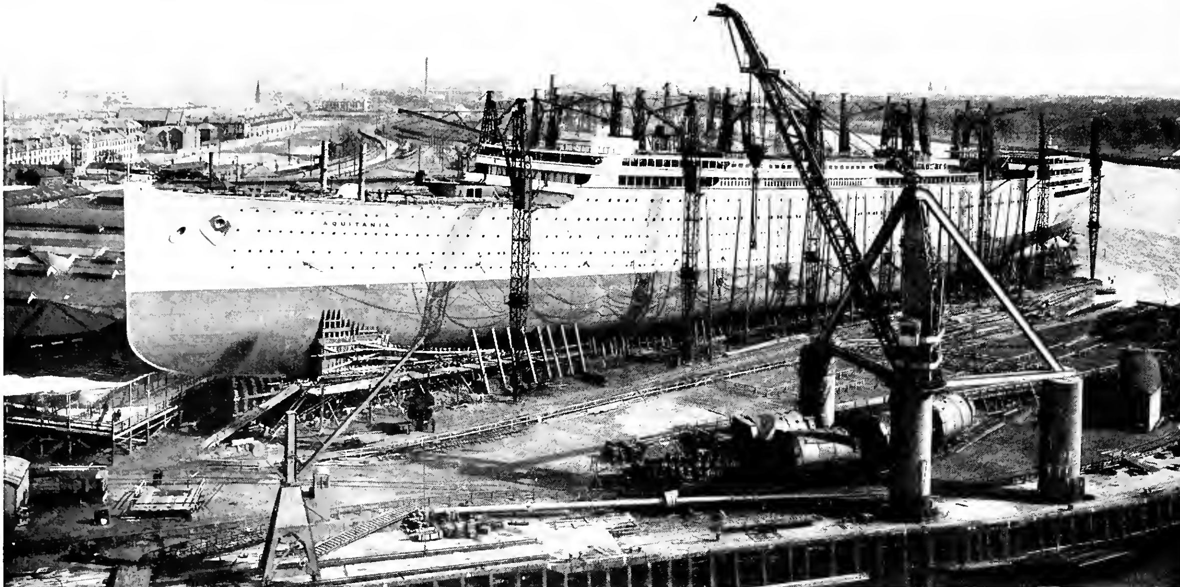


Photo supplied by Messrs. John Brown & Co., Ltd., Clydebank

THE CUNARD STEAMER "AQUITANIA" ON THE STOCKS

you, we have seen in 1913 the launching of an immense vessel, the Cunard steamer *Aquitania.* Still larger is the German ship *Imperator.* In these you have something to marvel at. Look how they dwarf the grand conception of Brunel and his *Great Eastern,* and are achieving a success where Brunel's mightiest effort spelt unhappy failure.

The old philosopher in the Book of Proverbs wrote: "There be three things which are too wonderful for me; yea, four which I know not: the way of an eagle in the air; the way of a serpent upon a rock; the way of a ship in the midst of the sea; and the way of a man with a maid." There is much, I think, for us still to learn in the "way of a ship in the midst of the sea," but we can, I think, already look forward to a few of the developments that the future has in store for us.

Steam as the motive power for ships is doomed, we may be confident, and it will be for the builders in the near future so to modify their ships that oil may be used in place of coal as fuel. I have made rather a point in this book of leaving machinery as much as possible on one side, so as to concentrate your attention on the broader aspects of engineering; but as the Diesel engine seems to me destined to play so prominent a part in the shipbuilding of the future, I think it may be well for us to consider the different powers of propulsion for the use of which the builder may be called upon to design his vessels. We will pass over the old days of the galley, where the vessel was driven along by banks of oars, and we will only mention sail to suggest that the day may not be so far distant after all when we shall see a return to sail for several classes of ships with other power as an auxiliary. To-day the pre-

eminence rests with steam, whether it is used to drive the great reciprocating engines with their heavy rods moving to and fro, or to drive turbines in a steady rhythmical motion in which the speed of the engines gives no special strain to the ship. The steam may be raised either from coal or oil, and until recently it was thought that the great advance would be the superseding of coal as a fuel by oil as a fuel. Then came the idea of what has wrongly been called the internal combustion engine, that should more rightly be described as the internal explosion engine, for by a triumph of engineering skill the problem of using an explosive to drive an engine has been solved, a problem that the engineers of the old days tried but failed to solve with gunpowder. As most of you know, the ordinary motor-car engines work by virtue of the fact that a mixture of petrol and air is brought and compressed in the cylinder, and then definitely exploded so as to drive the piston forward on its working stroke. We will pass over the idea of utilising electricity, and even gas, for as yet these seem to have no future before them for large vessels, and come to the last type of all, the type that I think we shall find will oust all others from the field, I mean the Diesel engine. Let us watch it at its work. The piston moves down about ninety per cent. of its working stroke and then two valves open, an exhaust valve and an inlet valve. The inlet valve admits a rush of compressed air which both scavenges the cylinder, driving out the exhaust gases, and supplies fresh air. Then the exhaust valve closes, and the piston returning compresses the air so that it is ready for the injection of oil at the top of the stroke. The extraordinary efficiency of this system is shown by the

fact that when a Diesel engine and a steam turbine were tried side by side at the Turin Exhibition, the two engines did the same amount of work, but the turbine consumed two and a half times the amount of fuel. The engine has already been tried at sea and proved satisfactory, and there seems no doubt but that the shipbuilder of the future will design vessels for these engines, and reap for the owners the advantages of increased cargo space, lessened cost of fuel, and a reduced wages bill.

I have referred already to the increased size of sea-going vessels, and to the probable development we may expect to see in their means of propulsion, and the next step, I imagine, will be to ensure that all boats of any reasonable size are equipped with a system of wireless telegraphy. It seems only yesterday that Mr. Marconi astonished the non-scientific world, and received the congratulations of men of science for having solved the problem of transmitting Hertzian waves through the ether of space, and we have seen now several occasions on which disasters at sea have either been minimised, as in the awful tragedy of the *Titanic*, or else altogether avoided. Wireless telegraphy requires to be further cheapened and improved, and the time will come when no vessel of considerable size will dream of putting to sea without a wireless installation on board. The chronometer will, to a large extent, though not entirely, be superseded, for the ships all over the ocean will receive their correct Greenwich time as often as is thought necessary direct from the Observatory, and in this way will have an apparatus more reliable than the chronometer, however skilfully it may have been constructed.

But we shall live to see still more elaborate precautions taken to ensure the safety of vessels at sea. Already many vessels carry an under-water telephone, whereby they can pick up the sound signals of lighthouses and light vessels in time of fog, and so navigate the seas with greater safety, being able by telephones placed on either side of the vessel to determine exactly the origin of the sounds they pick up.

When the *Titanic* went down with her heavy list of dead there were many proposals put forward for still further increasing the safety of ships and their passengers, and it may well be that one or other of the proposals then made will be incorporated by the shipbuilders. In the chapter on marine salvage we saw that one such idea was to strengthen the decks, and more especially the hatches of the vessels, so that if the ship received such a blow as the *Titanic* received, she should be able to remain afloat by having her weight carried on the deck above that where the damage has been done. Only recently I heard a striking instance of how conspicuously this is not the practice at present. One of the large vessels trading with the West Coast of Africa, after a splendid passage from the coast, met with bad weather after leaving the Bay. Her cargo shifted under the stress of the storms, and some of the barrels of palm oil that she was carrying broke through the hatches, and fell from deck to deck, being shattered in their fall. The loss of the oil was a trifling matter comparatively, and I only quote the incident to show you clearly that at present the builders, rightly or wrongly—and there is much to be said on both sides—do not consider it advisable so to strengthen their vessels that they

should be able to bear a heavy pressure on their hatches and decks.

Two suggestions were made as to the means that might be taken by ships to determine the near presence of icebergs by night. One of them I shall only mention, because I think the conditions at sea are such as to make it valueless. The idea of the inventor, who had good evidence of a sort to go on, was that the presence of a berg so lowers the temperature of the surrounding water that a sufficiently delicate thermometer would indicate the entrance of a ship into the danger zone. The other idea, put forward by the great inventor, Sir Hiram Maxim, is so ingenious that it seems at least to be worth a trial. Sir Hiram Maxim starts a description of his apparatus with an account of a not very well-known experiment in natural history. If a wild bird is set free in a room, it usually makes straight for the glass window, and being unable to see the glass, it dashes against it with such violence as to break its neck. A bat, however, behaves very differently. Like the bird, it is unable to see the glass, and starts flying towards it to escape, but when it is a short distance off it stops in its flight, realising, by what seems to be a sixth sense, that the transparent window is, after all, an obstacle in its path. It is only necessary to watch the bat attempting to escape to realise that the animal is puzzled by the different messages sent to its brain by the two sets of senses, for it keeps hovering near the glass and directing its flight towards it only to stop again and again as its "sixth sense" gives it a warning. The explanation of the bat's "sixth sense" is that it has a special organ enabling it to detect the echo of the vibrations sent out by the

beating of its wings, and when we remember that the bat is a nocturnal creature, it is only natural that it should place full reliance in a method that enables it to tell when it is liable to strike against a solid obstacle that it may find in its path.

With this as a guiding idea, Sir Hiram Maxim claims that it will be no very difficult task to equip a ship with a similar weapon. The first necessity, obviously, would be the apparatus for sending out waves. For this he suggests a modified form of siren, driven by steam that should give out sound waves of such low frequency as to be inaudible to the human ear. Such waves would, of course, be reflected like any other waves, and the inventor has found that they are amply sufficient to set a large diaphragm vibrating. To harness this diaphragm so that it should ring a warning bell, and at the same time record the number of its vibrations, would be an easy task, and the inventor contends, therefore, that there would be no difficulty in receiving any such waves that might come in the ship's path. Let us conceive now a large vessel travelling by night across the sea. Her steam siren would continually be sending out these soundless waves to dissipate themselves over the expanse of ocean. But suppose a solid body like an iceberg intervenes. At once some of these waves are reflected back according to well-known laws. The waves—which would carry a distance of as much as twenty miles—would return to the ship, and set the diaphragm in motion. An alarm bell would be rung on board, and the apparatus recording the extent of the vibrations would give the officer responsible a very good idea of the distance he was away from the obstacle. Practical

experiment alone can decide whether such an apparatus would behave as its inventor believes, but one must confess that the idea seems worth a trial.

From devices of this sort one comes naturally to consider the precautions taken to ensure the safety of passengers, even though the parent ship may meet with a terrible disaster. With life-jackets, lifebuoys and flare lifebuoys, I am not here concerned, for their provision hardly comes within the business of the shipbuilder, but the question of ship-boats is a problem that calls for his most serious attention. It is a simple matter to join in the general clamour and say that it is monstrous for a ship to go to sea without there being adequate facilities for saving life in the event of there being a catastrophe. But are we willing to pay the price? It is no use for us to try and put the burden on the shipbuilder. He is a business man, who will only carry on his trade if we can offer him a fair rate of profit, and if we, as members of the public, demand that he shall carry enough boats to take us off in the event of an accident, it is we who will have to make up the difference to him in the reckoned number of passengers carried. And when we have got our boats, how often do you think the conditions at sea will be such as they were in the case of the *Titanic* and it will be possible to have them launched?

The shipbuilder, we must remember, has all sorts of problems to consider in constructing a ship, and if we hamper him unduly, and produce our perfect ship in England, I am afraid there is a danger that passengers will refuse to pay the price, and will go by foreign lines, so that the last state of the matter will be worse than the first. All sorts of suggestions in this connection have, of course,

been made, and in several quarters men have girded at the luxury of the liner, and argued that safety should be placed in front of luxury, and that the accommodation given up to swimming-baths and so forth might be far better handed over to a further provision of boats. The shipping companies do not provide these luxuries just for the pleasure of doing so, but they play their part in the shipping business no less thoroughly than do the ship's engines. If we say we are prepared to pay the cost of extra boats, let us ask ourselves honestly how often we take the simple obvious precaution of insuring our life when we travel by rail.

Of the many ingenious contrivances suggested for increasing the accommodation available in case of a disaster, one is the idea of equipping the ship with a removable deck-house, so that the structure could be unbolted from the damaged portion of a ship, and then, when the rest of the ship went down, should float on the water like a raft. The idea is, of course, perfectly feasible, but I am not at all sure that if you had it carried into effect, you would not find that you had definitely weakened your ship as a whole. That is a danger that you have always to bear in mind, and for my part I think I would rather go to sea in a ship when the builders had so constructed her as to include every precaution that she should keep afloat, than in one where the utmost ingenuity had been displayed in devising means for saving my life when once I find myself tossing in the mid-Atlantic.

However this may be, it is a source of legitimate satisfaction to every Englishman that his country does lead the world to-day in shipbuilding. There are many ways in

which the truth of this could be brought out, but in no more striking way, I think, than by quoting to you, from *Whitaker's Almanack,* as I have Mr. Whitaker's permission to do, the list of the world's biggest ships, with the names of the companies by whom they are or have been owned.

EVOLUTION OF THE STEAMSHIP ON THE NORTH ATLANTIC

(1) Wood paddle-boats (3) Iron screw steamers
(2) Iron ,, (4) Steel ,,
(5) Steel steamships with more than one propeller.

Date	*Name of Steamer*	*Owners*	*Remarks*
1833	*Royal William* (1)	Quebec and Halifax S. N. Co.	From Pictou (N.S.); first to cross the Atlantic.
1838	*Sirius*	British and American Co.	From Cork, first departure from U.K.
1838	*Great Western* ..	Great Western S. N. Co.	From Bristol, first built for Atlantic.
1838	*Royal William* (2)	Transatlantic S. S. Co.	From Liverpool, first departure.
1840	*Britannia* ..	Cunard Line..	From Liverpool, first carried British mails.
1849	*Atlantic*.. ..	Collins Line ..	From New York, first carried U.S. mails.
1856	*Borussia* ..	Hamburg-American Line	From Hamburg, first carried U.S. mails.
1856	*Adriatic*.. ..	Collins Line ..	Last sailing of Line.
1856	*Persia* (2) ..	Cunard Line ..	First Cunard iron paddle steamer.
1858	*Bremen*	Norddeutscher Lloyd	From Bremen to New York.
1862	*Scotia*	Cunard Line ..	Last Cunard iron paddle steamer.
1845	*Great Britain* (3)	Great Western S. N. Co. ..	First Atlantic iron-screw steamer.

Date	*Name of Steamer*	*Owners*	*Remarks*
1850	*City of Glasgow* ..	Inman Line ..	First to carry steerage passengers.
1858	*Great Eastern* ..	East and Australian S.S. Co.	Paddle wheels and propeller.
1868	*Italy*	National Line	First Atlantic s.s. with comp. engines.
1869	*City of Brussels*	Inman Line ..	First Atlantic s.s. with steam steering gear.
1871	*Oceanic* (first) ..	White Star Line	First with 'midship saloon, etc.
1874	*Britannic* ..	White Star Line	First to exceed 5,000 tons, *Great Eastern* excepted.
1875	*City of Berlin* ..	Inman Line ..	First with electric light.
1879	*Arizona*	Guion Line ..	Watertight compartments floated her.
1881	*Alaska*	Guion Line ..	First "Ocean greyhound."
1883	*Oregon* (1) (2) ..	Guion Line Cunard Line	Sunk outside New York; everyone saved by N.D. Lloyd s.s. *Fulda*.
1879	*Buenos Ayrean* (4)	Allan Line ..	First Atlantic steel steamer.*
1881	*Servia*	Cunard Line ..	First Cunard steel steamer.
1881	*City of Rome* (1) (2)	Inman and Anchor	Fitted with three funnels.
1884	*America* ..	National Line	First and last express s.s. of Line.
1884	*Umbria, Etruria*	Cunard Line ..	First with 20 knots speed.
1886	*Aller*	Norddeutscher Lloyd	First triple-expansion express s.s.†

* Union Company of New Zealand's *Rotomohana*, 1,763 tons, was first ocean steel steamship, 1879.

† *Martello*, 2,432 tons, of Wilson Line, was first Atlantic cargo triple-expansion steamship, 1884.

Date	Name of Steamer	Owners	Remarks
1888	*City of New York* (5) (1)	Inman & International	First twin-screw ocean expresses.*
1888	*City of Paris* (2)	American Line	First to exceed 10,000 tons, *Great Eastern* excepted.
1889	*Teutonic* / *Majestic*	White Star Line	Designed as mercantile cruisers.
1890	*Fürst Bismarck*	Hamburg-American Line.	First under $6\frac{1}{2}$ days from Southampton.
1892	*La Touraine* ..	Compagnie Générale Trans.	Record Havre to New York, $6\frac{3}{4}$ days.
1893	*Campania* / *Lucania*	Cunard Line	*Lucania*: highest day's run, 562 knots, Liverpool to New York records.
1895	*St. Paul* / *St. Louis*	American Line	Largest express steamers ever built in America.
1897	*Kaiser Wilhelm der Grosse*	Norddeutscher Lloyd	Record day's run, 580 knots.
1899	*Oceanic*	White Star Line	Balanced engines. First to exceed 15,000 tons.
1900	*Deutschland* ..	Hamburg-American Line	Fastest ocean steamer to date.
1901	*Celtic*	White Star Line	First to exceed 20,000 tons.
1903	*Kaiser Wilhelm II.*	Norddeutscher Lloyd	Largest express steamer to date.
1904	*Victorian* ..	Allan Line ..	First fitted with turbine engines.
1907	*Lusitania* / *Mauretania*†	Cunard Line	Fitted with turbine engines.

* *Notting Hill*, 3,921 tons, of Twin-Screw Cargo Line, came out so engined, 1881.

† *Mauretania*, largest and fastest to date. Record day's run, 676 knots, January 25, 1911.

Date	*Name of Steamer*	*Owners*	*Remarks*
1908	*Laurentic* ..	White Star Line	14,892 tons, reciprocating engines with a low-pressure turbine.
1910	*Olympic*.. ..	White Star Line	45,324 tons.
1913	*Aquitania* ..	Cunard Line ..	47,000 tons, building.
1913	*Imperator* ..	Hamburg-American Line	50,000 tons, 880 by 98 by 59 feet.
1913	*Britannic* ..	White Star Line	Building.

CHAPTER XXIV

DOCKS, HARBOURS AND BREAKWATERS—AN ACCOUNT OF AN IMAGINARY VOYAGE, ILLUSTRATING SOME DIFFERENT TYPES

THE construction of docks, harbours and breakwaters is one of the heaviest tasks that fall to the lot of the engineer, for the conditions of the work necessitate his dealing with the most powerful and destructive of the weapons that Nature keeps stored in her arsenal—the sea. It is seldom, if ever, that he attempts the work unless Nature herself has been prodigal of special facilities. If we look round our coasts at the numerous harbours sheltering our shipping, and at the breakwaters that in some cases are necessary to protect the entrance to the harbours, you will see that in most cases, if not in all, the work of the engineer has been directed towards improving the natural facilities afforded by land-locked bays rather than creating facilities, when such did not before exist.

From the mechanical side of the work, sea building is mostly a question of giant cranes, monster steam scoops or navvies, or diving bells or divers. From the engineer's point of view the problem is one involving subtle mathematical calculations to determine what will be the pressure that his structures will be called upon to withstand, and how they can best be built to do their work. From the seaman's point of view the questions are the facilities they give for

entering and leaving, and the protection they afford in bad weather; while it is the duty of the business man who promotes them to determine whether they can effectually be made to pay by the volume of the traffic that they will attract. If I were to try and describe to you the difficulties of harbours and dock and breakwater construction, I should very soon find myself either repeating what I have already written in connection with bridge work and other subjects, or else branching aside from the main purpose of the work to speak to you of the wonderful machinery with which the docks are equipped for dealing with vast quantities of coal and goods that they are required to handle. I think I cannot therefore do better than follow an old-fashioned practice, and take you on an imaginary voyage. In this case our trip will be over country that I know from Burnham-on-Crouch to Southampton. The incidents I propose to write of have happened to me on one occasion or another, but I am putting them all into the one voyage, as they will illustrate fairly well the character of the work that the engineer has to achieve in building his harbours, his docks and his breakwaters.

It will be early in the morning when we get up—probably before light—and after a fairly hurried breakfast, which will be none the worse for being a bit hurried, we shall hoist all sail, and slip our moorings, and make for the open sea. It will take us some little trouble to pick up the Buxey Buoy, lying off the mouth of the river, but when we have made that we shall have no difficulty in rounding the Whitaker Beacon and getting straight on to the road for Sheerness, where we shall spend the night, even though it does mean getting a little bit out of the

way. The grey dawn changes to full daylight, and as we are making across the Thames estuary, with a light wind, luckily for us, we touch bottom, for we have fouled the sand. This means running out a kedge anchor, and pulling back onto it as soon as the tide rises—a troublesome business enough, but nothing very serious, as the tide is rising and we have only a light wind. It would be a serious matter though if we happened to be a big ship, and it was high water, and at the present moment it is one of the objects of the Port of London Authority to dredge a 30-foot channel from the mouth of the Thames to the locks to make the river accessible to all boats, no matter what the state of the tide.

At last our little vessel lifts with the tide, and this time we are on our way between the street of lights that yachtsmen speak of as the Piccadilly of the Medway, to our berth off Port Victoria. We have plenty of food on board, and we propose to tie up to a mooring buoy for the night, just as many bigger vessels than ourselves would do in the Port of London, with a view to unloading their cargo into lighters that would come alongside. Our next day will take us towards the Forelands, but when we have got out well past Herne Bay, which is useless, by the way, as a means of giving shelter, a high wind gets up, and we decide to put into Margate to let the breeze blow itself out. It is two hours after low water, and one of us who knows that Margate dries at low water, has an idea that the entrance will give us water, and so we decide to try for it, getting a very nasty bump, and sticking on the bar outside, with the waves threatening to break the back of our boat, until we have got off again into deep water, and the

tide has flowed sufficiently to give us an entrance. Margate is a type of harbour that is of little use except for fishing boats. On the occasion we went in, I remember that one of the great wooden piles had suffered from collision with a barge that had blundered into it, which one of the insurance companies would have to replace. It illustrates a feature of harbours that the engineers try to get over either by dredging, as they have done at Dover and elsewhere, or by means of gates that are closed at high water, as we shall see for ourselves when we reach Ramsgate.

Ramsgate has not got an over-good reputation, but for my own part I have never had any difficulty in entering it. There is the outer harbour with a great sand bank that dries at low water, and beyond it the inner harbour, where the water is kept imprisoned with a gate to work on the same principle as those we have seen at the Panama Canal. We may as well pass by Ramsgate as the wind is fair, and aim at making Dover for the night. Dover, as we see when we get near it, is one of the largest, if not the largest made harbour in the world. It has two great openings, and a basin that would hold the Channel Fleet, and, as we want to spend a day or two here, and it is low water when we arrive, we will run our boat aground—close to the entrance of a gate-protected dock, and go ashore for food.

The harbour people are friendly to yachts now at Dover, and as we have only just returned to our boat a little before high water, the harbour-master's tug gives us a hail, and offers to tow us to a berth. In the narrow waters of a harbour, steam is far preferable to sail, and we have no hesitation in accepting the tow, to find ourselves eventually close beside one of the Channel steamers

that has been lying up for a refit, and with our boat at a constant level night and day from the side of the quay. We see now the advantage of the gate-locked dock, for if we wished to discharge cargo, we should have no trouble from the rise and fall of the boat with the tide. Dover has had a fortune of money spent on it since the days of Henry VIII., one of the earliest monarchs to take an interest in the port, and it now has a magnificent Admiralty Harbour, 610 acres in area. It is fortunate though that we have gone into one of the protected docks, for if it comes on to blow, Dover Harbour only gives indifferent shelter to a small or even to a large boat, and we might as likely as not have found ourselves rolling about all night, as I have done before now there, in pretty considerable discomfort. The harbour, as it is, took long years to construct, and the engineers in charge preferred diving bells to divers, for with the diving bells the men are able to work for longer hours, and are not so much interfered with either by currents or by rough seas.

We are fortunate, when we want to start, in finding an easterly breeze instead of the prevailing westerly, for with the wind westerly against us we should have found a wicked sea running off Dungeness; but that obstacle is safely passed, and we start steering a compass course to the Royal Sovereign Lightship off Beachy Head, as we want to catch a sight of the *Oceana's* masts—which at the time of our voyage had not yet been blown up as an obstruction to Channel traffic. The wind falls light, but we struggle on, meeting a French pilot and the Admiralty yacht among other boats on our course, until at last, when the sun is getting low on the horizon, we sight at once the masts of

the *Oceana* and the *Royal Sovereign* lying beyond her. There is a nasty troubled sea boiling over the shallow water in which the *Oceana* lies, and we are not sorry to bear away for Newhaven, which we make before dark. For my own part, I have always found Newhaven the easiest of ports to leave, and the hardest to enter, as when you come in you are extraordinarily apt to lose your wind, and drift aimlessly in the harbour. On the day I am thinking of I was single-handed, and giving the tiller to a boy I picked up at the entrance—I was reducing sail, when a puff caught us, and he ran the bowsprit straight into one of the side piers, so that with a crash the bitts were taken clean out of the boat. It is a good safe place to leave a boat in, though, for there is a special yacht basin, but commercial vessels have to rise and fall with the whole range of the tide. The breakwater is a solid enough structure, giving good protection from the prevailing westerly breezes, and stretching out for about a mile to sea, the great drawback to the place being that a bar forms over the harbour-mouth, preventing ships having a large draught from making the port except at certain times of the tide, an evil that will probably have, in the course of time, to be rectified by dredging, or by the construction of a specially designed system of breakwaters. We have a long way still to go, however, before reaching Southampton, and though the wind is a bit light, we must do our best, so after one night in Newhaven, we cast off, with the good wishes of one of the harbour-master's men, to try at least to make the Isle of Wight. But when we are off Brighton it falls a flat calm, and there is nothing for it but to anchor with Brighton in the distance, and wait for a breeze or

a change of the tide to help us along. Both, as not infrequently, come together, but only in time for us to make Shoreham, which, like most of the south coast harbours, is a tidal harbour. Here we learn for ourselves the real meaning of a tidal harbour, and the reasons why it is an advantage to be safe within the dock gates, for though when we berthed our boat we found it an easy matter to step ashore from her deck, when we return to her at low water we find her lying beneath our feet and already straining at her cables. For us it merely means a scramble down on to the deck and a hurried slacking of our ropes, but for a cargo boat wishing to load or unload cargo, such shifting up and down proves a very troublesome business, and the tidal harbour is therefore, if possible, avoided in dock construction.

Having made so poor a journey the day before, we make an early start the next day, and as the wind is light, we find ourselves forced to anchor in the entrance, being unable to make our way over the tide, and philosophically set about cooking breakfast. No sooner is the stove alight than a puff of wind comes, and it is a case of sacrificing breakfast to get on our way. And here we find ourselves inconvenienced by the fact that the engineers who constructed Shoreham Harbour, though they have followed one of the recognised practices of harbour builders, and arranged that the current should sweep across the entrance of the harbour, rather than that it should make its way up and down the entrance, and thereby unduly retard or accelerate the speed of vessels making the harbour, were unable to avoid a nasty eddy that almost brings us into collision with the pier. We have had a narrow escape of

breaking our bowsprit, our breakfast has been spoiled, but that is no matter, for we are out at sea again with a fair wind, too, for Southampton.

We will take an outside course to-day, for the glass stands high, and we want to avoid the under water mole that has been built off Portsmouth to prevent a hostile fleet creeping up under cover of the shore in the darkness to deliver an attack. With a good following breeze, for the wind has freshened, we race up the Solent, passing the long line of steamers moored in this finest of natural harbours, and passing the great docks and warehouses of Southampton, drop anchor just off Pickett's yard, the yard from which Mr. E. F. Knight sailed in his memorable cruise on the *Falcon*.

In the short space of this voyage we have seen most of the various type of docks, harbours and breakwaters that have been built to subserve their different purposes throughout the country, and indeed, throughout the world. We need only use the knowledge we have got of the way the workmen and engineers construct lighthouses and bridges, to imagine for ourselves how these great works have been brought to a successful issue, the preparing of the foundations, the laying of the heavy blocks of material, the difficulties involved through the sea breaking in on unfinished works, and the elaborate organisation required. At the moment we are witnessing the progress of a rapid evolution that in the middle of the last century was checked through the ill-fated career of the monster created before her time, the *Great Eastern*. Big ships, our merchants are realising now to the full, are cheap ships, and with the growth in our ships our harbours have to keep pace.

London is already making accommodation for such mighty vessels as the new Cunarder, the *Aquitania*, and as the competition between the different docks and ports means in essence the competition between the different railway companies for the capturing of the goods traffic, we may be assured that they will not rest until they have got them to the highest pitch of efficiency that human ingenuity can achieve.

CHAPTER XXV

THE MAKING OF AN ENGINEER

Poeta nascitur, non fit. The proverb may be true of the poet or not, but there can be no doubt that the successful engineer must be born with the taste for engineering. You can take two brothers, and give each of them a box of tools. One of them will turn out rabbit-hutches, or whatever his heart yearns for, true and well constructed; the other will do little more than spoil good wood, having his angles all awry, his nails driven in crooked, and the result shapeless, untidy, ill-adapted to its purpose. There is the one class of mind that can see the drift of geometry almost at a glance, whereas the other type will find the problems a meaningless jargon of figures and letters to be learnt parrot-like at the dictates of an unsympathetic master. In the same way, there will be some who have almost the same sympathy for a machine as others have for an animal, and seem able to coax the most broken-down engine to do what they require of it. Decidedly, an engineer is born, not made, but those who wish to take up engineering as a career have to superimpose on a natural bent an elaborate training.

Thinking it might interest some of you, now that you have read something of the work that the engineer is called upon to do, to know of the way in which he is made, I approached the Secretary of University College, London,

for special information on the subject. The Engineering School at University College is by no means the largest of the engineering schools, even in London, but it was the pioneer in engineering education in London, and is still progressive and energetic, while it is sending trained engineers into all parts of the world; the teaching it gives furnishes a good illustration of the way in which the raw material of the man is turned into the finished product of the engineer. The first thing one has to realise clearly is that the theoretical and practical training given in such a place as University College is not intended to supersede such necessary practical training as can only be properly acquired in the office, workshop or factory. In other words, engineering, like all other professions, if you get down to bed-rock, can only be learnt by actual practice under bona fide working conditions. The engineer, if he is to know his business, must go to the shops, as the great engineering works are called, and learn to handle a file and cut a screw, and get something of that intimate knowledge of craftsmanship in which the true workman takes a pride.

But the true engineer is different from a craftsman—I think I might fairly write, is something greater than the craftsman—for, in addition to a knowledge of the engineering craft, he must have a full understanding of the principles that govern engineering practice. And to do this he has to go through a wide training. Just consider the requirements that an institution such as University College demands of the men who wish to enter as students in the Faculty of Engineering. They have to show a competent knowledge of English, a knowledge of mathematics, includ-

ing the binomial theorem and elementary trigonometry, and profess either a language and an elementary science, or two elementary sciences. In other words, the would-be engineer must be a boy who has passed through the modern side of his school at least with credit. With this as a foundation the College feels that it is possible to give a man the theoretical training which he requires as an engineer. Three direct branches of engineering are recognised—mechanical, electrical, and civil and municipal engineering—and no matter which the branch selected, a three years' training in the theoretical aspects of the subject is the minimum required. For the first year the training in the three is identical. Broadly, it may be said to consist in what from the school standpoint would be regarded as higher mathematics, in drawing and the application of graphical methods to mathematical and engineering problems, in mechanics and physics, and in a study of metals, building materials and the drawing of machinery. This does not, you may think, sound a very formidable list, and I do not propose to bother you with the details of a full syllabus; but, to give you some idea that the engineer is expected to get a pretty thorough grasp of elementary scientific principles, I have selected the syllabus of one of these subjects—mechanics—for reproduction here. It is as follows:—

MECHANICS OF SOLIDS.—Uniform and Accelerated Motion of a Particle. Force and Mass. Composition and Resolution of Forces in One Plane at a Point. Moments. Centres of Mass. Forces acting on Rigid Bodies, including Couples. Conditions of Equilibrium, Work and Energy. Friction. Impact. Projectiles. Centripetal Force. The Simple

Pendulum. Simple Harmonic Oscillations. Moments of Inertia.

Mechanics of Fluids.—Density. Pressure in Liquids at Rest. Centres of Pressure. Principles of Archimedes. Specific Gravities and their Measurements. Equilibrium and Stability of Floating Bodies. Metacentres. Pressure of Gases. Barometers. Pumps. Simple Problems connected with the Flow of Liquids.

It is not until the second year that there begins to be a differentiation in the work that the students undertake, and even then such differentiation as there is is on the slightest lines. The men study specially engineering drawing and machine design; under the subject, junior engineering, they attend lectures on the various properties of materials, on the nature of stresses and strains, on the curious phenomenon of fatigue in metals, on the special behaviour of different forms of structure, on fuels, on the properties of steam and gases, on the elements of steam, gas and oil engines, and on the various theories that underlie different machines and mechanisms. In this year, too, the students do a certain amount of experimental work in engineering. In his comments to me on the importance of this branch of the work, the Secretary of the College said:

"The engineering laboratory is intended to provide systematic instruction to students and young engineers in the experimental methods which serve for determining the numerical data employed in engineering calculations, and also to familiarise them with the strength and other physical properties of the chief materials used in construction. The importance of such instruction is twofold. In the first place, the exact value of any numerical results derived

from experiment and the limits within which they may be safely trusted, can be rightly estimated only by those who have some practical and personal acquaintance with experimental processes of the kind employed in obtaining these results. In the second place, engineers are continually called upon to deal with new problems, or problems in regard to which some essential data are altogether wanting, and they are, therefore, very often compelled to make special experiments for their own guidance. It is obvious, however, that in such cases the probability of their obtaining accurate and trustworthy results will be much greater if their previous training has made them practically acquainted with the art of experimenting, and with the methods that have been successfully adopted by others in dealing with analogous questions."

I asked him further to give me some information as to the actual machinery of which the engineering student was expected to get a thorough mastery, and he pointed out that as regards this general engineering, the student was expected to be familiar with all the different machines contained in the laboratory. Now, as is shown in the syllabus of the College, the laboratory contains a large testing machine (capable of exerting a pull of 100,000 lbs.), with specially arranged appliances for making accurate measurements of extensions, compressions, deflections, etc.; an hydraulic accumulator (loaded to 1½ tons per square inch), from which the testing machine can be worked, connected with a special pump, driven by a gas-engine; apparatus for drawing autographic stress-strain diagrams; a 70-ton testing machine, specially arranged for compression and cross-breaking tests; smaller testing-machines, specially arranged

for cement, transverse, impact, torsional, repeated load, oil tests and testing of long struts respectively; a compound condensing steam-engine working up to 40 ind. horse-power, specially arranged for experimental purposes, with condenser, measuring tanks, indicators, dynamometers, etc.; a high-speed 12 ind. horse-power compound engine, and two small engines, also arranged for testing; a de Laval steam turbine, with condenser and Edwards air-pump; a steel multi-tubular steam-boiler, with calorimeters for fuel tests, etc.; a Babcock and Wilcox 100 horse-power water-tube boiler; a refrigerator; a gas-fired boiler; a gas-engine working up to 8 ind. horse-power, arranged for testing purposes; a petrol motor; two standard gas meters and other fittings; a gas calorimeter; a mercury column and fittings for testing gauges, indicators, etc.; brake dynamometers; transmission dynamometers; pulsometer-pump; two air-compressors; steam-pumps; micro-photographic apparatus for the study of metals; 15 b.h.p. motor, driving a low lift centrifugal pump; apparatus for measurements of the flow of water over weirs, and the resistance of pipes, valves, bends, etc.; machine tools, (lathes, shaping machine, drilling machine, planing machine, milling machine, universal milling machine, pneumatic tools, etc.), specially designed apparatus for conducting experiments of the kind just mentioned, as well as the necessary tools and appliances for working in wood and metal, preparing apparatus and specimens, along with standard gauges and measuring-apparatus.

Apart from making tests with the machines contained in this formidable list, in addition, all students have to continue their mathematical work, and, further, to study

physics. The mechanical engineers also go on with graphics and electrical engineering, both practical and theoretical; the electrical engineers do special electrical experiments, in addition to the other work, while the civil and mechanical engineers have a special course in graphics, geology and surveying.

In the last year of their course there is a complete differentiation between the different branches of the subject, and it would take up too much space, and, I think, would convey very little more to you than I have done at present, if I were to go further into details. I will quote, however, to you a further comment about the education of the engineer that was made to me by the Secretary of the College: "There is," he said, "another important aspect of the training of the engineer, namely, the education other than the purely professional or technical training which he may expect to derive from a college course. At University College the Engineering Department is not an isolated unit, but is in close touch with the other Faculties of the College, Arts, Laws, Science, and Medical Sciences. In this way the engineering student is brought into contact both in this college course itself and also in the social and athletic life of the college with men preparing for other professions than his own. Such intercourse with men of other faculties and different pursuits cannot fail to be stimulating, and helps to prevent a narrowness of outlook which is the danger with men whose intercourse is confined to men of their own branch of study."

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In writing as I have done in the preceding pages, I hope that I may have brought before you some aspects of engi-

neering with which you were previously unfamiliar, but which are eventually destined to form the work to which some of you will devote yourselves. And if ever there was a life thoroughly worth living it is that of the engineer, provided the individual has the necessary aptitude for his task. In engineering, man strides upright into his rightful heritage. He is like Ezekiel in the vision, breathing life into the dry bones. Having lifeless matter for his medium, he expresses his own individuality by changing it into forms that under his direction mould or modify the face of the world. It is the engineer who is the great empire-builder, and it is primarily he on whom the country must depend both for its material progress and for its power to defend itself against attack. Great Britain has won a proud place among the nations through her engineering exploits, and the present looks confidently to the future to carry on and to further the tradition that has been handed down from the past. We can imagine ourselves to-day as stationed somewhere on the course of a torch race that has been in progress from the earliest times, and of which the end lies far below the horizon of the future. The torch that was handed to the first of the long line of runners has been carried towards the goal by countless engineers, and it is only the very few who have left behind them even the memory of their achievements. What lies at the ultimate goal none of us can tell, but each stage in the race carries us to a position where we have a greater mastery than we had before over the brute forces of Nature. The torch is carried forward by many others than engineers. Its progress is hastened by all who honestly attempt to do the best work of which

they are capable; but the engineer is peculiarly fortunate in that he can see before him in tangible form the fruits of his labours, and, if he has the eye of imagination, he can realise that it is the privilege of his profession to increase indefinitely the opportunities for a complete life. The purpose of this book will have been achieved if it has thrown some light on this aspect of engineering, if it has shown in part something of the great services that the engineer has rendered, and is daily being called upon to render, to his fellow-men.

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